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INVESTIGATION OF SHOREBASED POWERLINE TRANSIENTS. PHASE II.(U)
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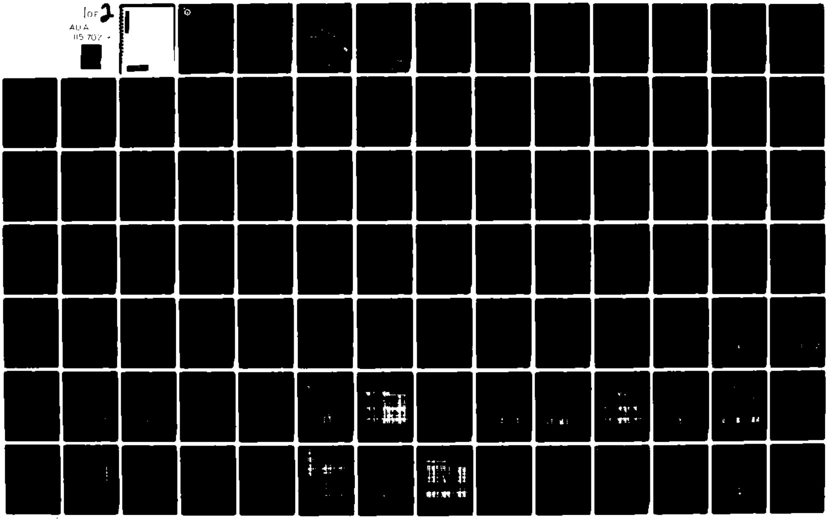

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DEPARTMENT OF THE NAVY

**NAVAL ELECTRONIC SYSTEMS ENGINEERING ACTIVITY**

Saint Inigoes, Maryland 20684

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21 Apr 1982

From: Commanding Officer, Naval Electronic Systems Engineering Activity, St. Inigoes
To: Distribution

Subj: Phase II Final Report on the Investigation of Shorebased Powerline Transients; forwarding of

Ref: (a) NAVMAT EMC/WARC Task No. 82-10

Encl: (1) Sachs/Freeman Associates, Inc. Phase II Final Report, "Investigation of Shorebased Powerline Transients"

1. The Chief of Naval Material, by reference (a), requested that NESEA determine the extent of powerline transients at operational Navy shore facilities. This task was completed by NESEA Code 0263 and a report based on the results was prepared under contract by Sachs/Freeman Associates, Inc.

2. The report forwarded as enclosure (1) was reviewed by NESEA Code 0263 personnel for technical accuracy and thoroughness and is considered acceptable. If there are any questions or comments, contact Mr. Lewis Bachman, NESEA Code 0263, on Autovon 356-3512, extension 8263, or commercial (301) 862-8263.

R. E. Waxman

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# PHASE II FINAL REPORT

# INVESTIGATION OF

# SHOREBASED POWERLINE TRANSIENTS

Rept. Date: Sept. 1981

## FOREWORD

This report is one of a series which has been and will be issued during this investigation to determine the nature and extent of power line transients on U. S. Navy ships, shore stations, and aircraft. It is the final report of the shorebased investigation for identifying power line transients (Phase II); a similar previous report was issued for the shipboard investigation (Phase I), and a future report will be issued for aircraft (Phase III). Other reports to be issued based on the results of Phases I, II, III together will cover: power system models; test plans and procedures for establishing transient susceptibility levels; and test methods specifications consistent with MIL-STD-461/462.

The project is sponsored by Code MAT 08DE, Naval Material Command, Washington, DC and has been funded under the EMC/WARC Programs 65803N Project Z0706, Tasks 78-1, 79-13, 80-10 and 81-10 (NESEA Project Nos. 78-15-26, 79-05-26, 80-02-06 and 81-02-26).

The Task Manager for the Naval Electronic Systems Command, Washington, DC is Mr. S. Caine (Code 51024).

The Program Manager for the Naval Electronic Systems Engineering Activity is Mr. L. Bachman (Code 0263). The NESEA project personnel are Mr. M. Gullberg, Mr. F. Stricker, Mr. D. Choporis, and Mr. A. Freeland.

This report was prepared for NESEA under Contract #N00421-79-C-0183 by Sachs/Freeman Associates, Inc., Bowie, Maryland 20715. SFA personnel are Mr. H. Sachs, Mr. D. Oldson, Mr. R. Hall, Mr. C. Tsonis and Mr. M. Morenz.

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# EXECUTIVE SUMMARY

## IDENTIFICATION OF SHORE FACILITY POWER LINE TRANSIENTS


The purpose of this investigation was to determine the extent of power line transients at operational Navy shore facilities. This was done by conducting extensive measurements using various power line monitoring and recording equipments. The effort constituted the second phase of a multiphase effort to measure power line transients on Navy ships, shore facilities and aircraft.

This report presents the results of measurements performed at thirteen (13) Navy shore facilities over a period of approximately two years. The measurements provided a large amount of data (about 27,500 transients over approximately 134,700 instrumented test hours) that were analyzed to determine the frequency and severity of power line transients at these sites. The facilities involved were:

- NAS, Key West, FL
- NAS, Patuxent River, MD
- US Naval Observatory, Washington, DC
- Naval Base, Norfolk, VA
- Radar Site, San Juan, PR
- Fleet Training Center, Dam Neck, VA
- Naval Amphibious Base, Little Creek, VA
- NAS, Oceana, VA
- Radar Site, St. Thomas VI
- Eglin AFB, FL
- NAS, Miramar, CA
- NAS, North Island, CA
- NAVCOMSTA, Diego Garcia, Indian Ocean

The approach used in the performance of this investigation was to first reduce the data which was collected by NESEA and then analyze this data with respect to several pertinent parameters. Over 94% of the data compiled by NESEA for the project was acquired using Dranetz Model 606-3 Power Line Disturbance Monitors; the remainder of the information was obtained using the Nicolet Model 2090-3 Digital Storage Oscilloscope. The tables and curves generated for Sections II and III and Appendix A of this report are based on the Dranetz data; a summary

of the Nicolet data results accompanied by representative photographs is provided in Section 4 of this report.

Having compiled, sorted, and further reduced the data cited above, SFA analyzed this data taking into account various factors which may be characteristic to transient behavior, such as location, voltage type (120/460V), transformer proximity, mean time between transients, etc. The results of this data analysis were then tabulated, graphically-displayed, and elaborated on in the final documentation of this effort.

A number of conclusions may be derived directly from the transient data analysis. They are as follows:

a. Although four line-voltage configurations were monitored at one time or another in the course of this effort, namely 120-volt line-to ground, 120-volt line-to-line (208V), 280-volt and 460-volt power lines; 88% of the data was recorded on 120-volt lines in the line-to-ground or common mode, the mode for which the results of this analysis may best be applied.

b. Among the thirteen shore facilities visited, the extent to which transients occurred varied considerably. The highest transient rates were found at specific locations at NAS Key West, FL and the Anti-Personnel Intrusion Test Site, Eglin AFB, FL, corresponding to almost two transients/hour. However, the highest level transients occurred at the St. Thomas Radar Site, VI on the power-line feeding the antenna drive system.

c. On Dranetz equipment, a peak transient amplitude maximum of 872 volts was recorded on 120-volt lines, while and 1184-volt transient maximum was recorded on 460-volt lines. Both of these transient maxima occurred at NAS Oceana, VA.

d. The Nicolet equipment, which was employed on 120-volt lines, recorded a maximum transient amplitude of 2976 volts at the St. Thomas, VI Antenna Location.

e. In general, higher transient amplitudes were recorded on Nicolet equipment than on Dranetz. A contributing factor to this phenomenon may be the minimum 0.5 μsec impulse duration limitation for the Dranetz device. Most of the higher level transients recorded by Nicolet Oscilloscopes had pulse durations of approximately 0.3 μsec.

f. For the composite Drantez statistics, approximately 53% of all the transients recorded had peak amplitudes between 50 and 100 volts, 46% had amplitudes between 100 and 500 volts, and 0.1% were recorded with amplitudes between 500 and 1000V; less than 0.01% of these occurred with amplitudes greater than 1000 volts.

g. Most of the cumulative probability distribution functions calculated for the various locations and sites exhibited a linear distribution when plotted on log-log paper. However, when the composite 120-volt site statistics were compiled, the cumulative probability density function exhibited a linear distribution when plotted on probability paper, signifying a normal distribution of the composite 120-volt data.

h. Although a limited amount of Nicolet data was collected in comparison with the amount of Dranetz data, significant information was obtained with respect to the rise time, pulse duration, transient energy; etc., which was not obtainable from the Dranetz statistics.

i. The highest energy level encountered on transients measured with Nicolet Oscilloscopes located at the shore facilities was 1.9 millijoules; this is in contrast to the Phase I shipboard report, for which the maximum shipboard transient energy encountered was 4.2 microjoules. This should not be construed as implying that shore-based transients contain more energy than their shipboard counterparts, since the data sampling was fairly limited in both cases.

j. Ac transients can have significant effects on dc power lines; in one situation encountered during this study, a transient of almost twice the dc line voltage occurred concurrently with a recorded ac transient.

k. Much higher level transients were observed during this investigation than were encountered as part of the shipboard effort (including ships operating from shore power). However, the cumulative statistics in both cases conformed to normal distributions.

l. Based on a limited amount of data involving transient behavior on both the primary and secondary sides of isolation and step-down transformers, it appears that transformers act as fair transient suppression devices. It was not uncommon to find a transient on one side of the transformer not being of sufficient level to be recorded on the other side of the transformer.

RECOMMENDATIONS

Based on the conclusions set forth above, the following recommendations are made:

a. That this report be used as the basis for modifying MIL-STD-461 ( ) to reflect the high amplitude, narrow duration shorebased transients.

b. That additional shorebased tests be performed that provide simultaneous voltage and current waveform measurements for determining transient energy content. Present data is not of sufficient quantity to establish statistical validity on transient energy levels.

c. In view of the fact that most high amplitude transients were of short duration (0.3 μsec or less), it is recommended that additional tests be performed to determine the extent to which the bandwidth limitations of the Dranetz 606-3 and Nicolet 2090-3 affected the results obtained. To do this it will be necessary to employ a wider bandwidth non-sampling storage oscilloscope at the shore facility, and to take scope photographs directly. Equipment to do this is readily available.

d. That additional testing of the effects of transformers on transients be performed, so that quantitative indications of transformer transient suppression can be obtained.

e. Finally, that a Nicolet Model 446A Fast Fourier Transform (FFT) Computing Spectrum Analyzer be added to the test instrumentation with the Nicolet Model 3090-3 Digital Oscilloscope to compute and display frequency spectra for current and voltage transient waveforms. The spectral data can then be used to compute power line impedance as a function of frequency.

## SECTION I

## INTRODUCTION & BACKGROUND

### 1.1 INTRODUCTION

The purpose of this investigation was to determine the extent of power line transients at operational Navy shore facilities. This was done by conducting extensive measurements using various power line monitoring and recording equipments. The effort constituted the second phase of a multiphase effort to measure power line transients on Navy ships, shore facilities and aircraft.

This report presents the results of measurements performed at thirteen (13) Navy shore facilities over a period of approximately two years. The measurements provided a large amount of data (about 27,500 transients over approximately 134,700 instrumented test hours) that were analyzed to determine the frequency and severity of power line transients at these sites.

The information contained in this report includes a description of the test approach, a summary of the data that was obtained, and a discussion of the data reduction that was performed. Other supporting material pertinent to this investigation is contained in report appendices.

The tests documented in this report were planned and conducted by representatives of the Naval Electronic Systems Engineering Activity (NESEA), St. Inigoes Maryland. Sachs/Freeman Associates, Inc. of Bowie, Maryland performed the data reduction and report preparation tasks under Contract N00421-79-C-0183 administered by the Naval Air Station, Patuxent River.

This investigation would not have been possible without the excellent cooperation provided by the Commanding Officers at the activities on which power line transient tests were performed. Without exception, these individuals showed an appreciation for the purpose and goals of this project, by allowing NESEA test

engineers broad flexibilities in testing locations, alloting times during which tests could be performed, and providing assistance in many forms, all within requirements for safety of personnel at the base.

## 1.2 BACKGROUND

Power line transients have been an area of concern for engineers and users of electrical equipment almost since electric power first became available. Since 1923 papers have been published on power line transients.[1] The subject continues to be of interest today, primarily because of the increase in the number of devices susceptible to power line transient effects.

Power line transient susceptibility requirements were first quantified by the U.S. Government in MIL-STD-826 in 1964. That document prescribed conducted and radiated interference and susceptibility tests for military electrical and electronic equipments, and included a transient susceptibility test as one of three power line conducted susceptibility tests to be performed on the test item. The transient susceptibility test consisted of applying 50-volt, 10-usec, positive and negative pulses to ac and dc power lines entering the test item. In MIL-STD-826A the test voltage amplitude was increased to twice the line voltage or 100 volts, whichever is smaller, for ac power lines; and to 56 volts for dc power lines. The military requirement for transient susceptibility testing as defined in MIL-STD-461A was the same as that defined in MIL-STD-826A. Recently issued MIL-STD-461B broadens the transient susceptibility test to incorporate peak amplitudes to 400 volts and pulse durations as low as 0.15 usec, depending on the particular class of power line involved; for Navy ground facilities, value of 400 volts and 5 usec are typical.

---

[1]IEEE Committee Report, "Bibliography on Surge Voltages in AC Power Circuits Rated 600 Volts and Less," IEEE Trans. on Power Apparatus and Systems, Vol. PAS-89, No. 6, pp. 1056-1061, July/August 1970.

Power line transients are of more concern today than ever before because of the widespread use of discrete semiconductor components and integrated circuits in electrical and electronic equipments. The trend for the future is for increased use of semiconductor electronics in more complex and compact devices, so that component burnout from transient signals is of serious concern. Equipments with improved sensitivities will be more vulnerable, and digital equipments will be subject to data corruption. Thus the risk of upset or damage to utilization equipments from power line transients will increase in the future unless steps are taken to protect these equipments.

It is important to understand the processes that generate power line transients and the mechanisms by which they affect various utilization equipments. Power line transients can be caused by the power system, utilization equipment or external phenomena, although most are caused by switching utilization equipment on and off the line. Unfortunately, the electrical parameters associated with low voltage power systems that relate to transient performance are not well defined, and this makes it difficult to predict transient phenomena. Also, the withstand capabilities or damage potentials of various utilization equipments are not well established, which makes it difficult to specify protection requirements.

There is a diversity of transient control requirements being applied today or proposed, as evidenced in Table 1-1. Amplitude, duration and repetition rate vary dramatically between specifications or standards. Rise time, load impedance and maximum available energy vary less dramatically. These differences in control approaches occur for a number of reasons, including the particular specification application involved, the degree to which the specification deals with utilization equipment failure or degradation, and the state-of-the-art of transient test equipment development. The applicability of any of the specifications or standards in Table 1-1 can be judged by the results presented in this report.

TABLE 1-1

POWER LINE TRANSIENT LIMITS

| SPEC. OR STANDARD | PEAK AMPL. (Volts) | RISE TIME (μsec) | DURATION (μsec) | REP. RATE (pps) | LOAD IMPED. (ohms) | TEST WAVEFORM | MAX. AVAIL. ENERGY (Joules) |
|---|---|---|---|---|---|---|---|
| IEEE STD 472-1974 | 2500-3000 | | | 50 | 150 | Damped sinusoid, 1-1.5 MHz osc. rate, 50% down in 6 μsec | |
| SAE-AE4 AIR 1499 (Proposed) | 600 | 0.1 | 1 | 9 | 50 | NA | |
| MIL-STD-461B | 100 - 400, depending on equipment class | | 0.15 - 10 depending on equipment class | | | Under-damped sinusoid, rise-time about 20% of duration | |
| MIL-STD-1399 | 2500 | 1.5 | 40 | | 150 | Damped sinusoid, 0.1-0.5 MHz osc. rate | |
| Burroughs 1257-5700 | 500-1700 | | 1000 | 16 | | NA | |

TABLE 1-1 (CONT'D)

**POWER LINE TRANSIENT LIMITS**

| SPEC. OR STANDARD | PEAK AMPL. (Volts) | RISE TIME (μsec) | DURATION (μsec) | REP. RATE (pps) | LOAD IMPED. (ohms) | TEST WAVEFORM | MAX. AVAIL. ENERGY (Joules) |
|---|---|---|---|---|---|---|---|
| IEC (Proposed) | 1000-2500 | | | 400 | 100 | Damped sinusoid, 1 MHz osc. rate, 50% down in 6 μsec | |
| EDF (France) (Proposed) | | | | 40-300 | 50 | Damped sinusoid, 1 KHz - 1 MHz osc. rate, 50% down in 6 μsec | |
| ENEL (Italy) (Proposed) | | 1 | | 200 | | Damped sinusoid, 1 MHz osc. rate, 50% down in 6 μsec | |
| Ontario Hydro C-5043-7 | 5000 | 0.5-10 | | 400 | 30-150 | Damped sinusoid, 0.1-2 MHz osc. rate, 50% down in 6 μsec | |

TABLE 1-1 (CONT'D)

**POWER LINE TRANSIENT LIMITS**

| SPEC. OR STANDARD | PEAK AMPL. (Volts) | RISE TIME (μsec) | DURATION (μsec) | REP. RATE (pps) | LOAD IMPED. (ohms) | TEST WAVEFORM | MAX. AVAIL. ENERGY (Joules) |
|---|---|---|---|---|---|---|---|
| Nat'l Weather Service (Proposed, 1978) | 700-1200 | 0.1 | | 9 | 100 | Damped sinusoid, 1-1.5 MHz osc. rate, 50% down in 6 μsec | 0.15 |
| Pearlston (Proposed) | 50 | | 10 | | | Single pulse with RC decay | 0.1 |

There has been a significant amount of effort expended in the past 10 to 12 years investigating power line transient characteristics and developing transient control requirements.[1,2] A portion of this work has been applied specifically to shipboard power line transients.[3,4,5] In addition to these transient investigations, data collection and analysis has been performed for shipboard sag, surge and interrupt data collected by the Navy.[6]

## 1.3 OBJECTIVE

The objective of this effort was to reduce and analyze the power line transient data collected by NESEA at thirteen (13) shore facilities that were suspected of having transient problems and prepare a report documenting the observed behavior of these transients with respect to identifiable quantities such as location, voltage type (120/460V), transformer proximity, transient duration, mean time between transients, etc. These facilities include the following:

- NAS, Key West, FL
- NAS, Patuxent River, MD
- US Naval Observatory, Washington, DC
- Naval Base, Norfolk, VA
- Radar Site, San Juan, PR
- Fleet Training Center, Dam Neck, VA
- Naval Amphibious Base, Little Creek, VA
- NAS, Oceana, VA
- Radar Site, St. Thomas, VI
- Eglin AFB, FL
- NAS, Miramar, CA
- NAS, North Island, CA
- NAVCOMSTA, Diego Garcia, Indian Ocean

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[1] Kajihara, H.H. and Giorgi, E., "Susceptibility of Selected Communication Equipment to Electrical Transients," Tech. Rept. R665, Naval Civil Engineering Laboratory, Port Hueneme, CA, February 1970.

[2] Smith, M.N., "An Experimental Investigation for Determining Susceptibility Limits and Techniques for Desensitization of Solid State Electronic Equipment to Power Line Transients," Tech. Note N-1256, Naval Civil Engineering Laboratory, Port Hueneme, CA, April 1973.

[3] Connova, S.F., "Investigation of Short-Time Voltage Transients in Shipboard Electrical Power Systems," Naval Applied Science Laboratory, Brooklyn, NY, Project 940-55, 12 September 1968.

[4] Connova, S.F., "Short-Time Voltage Transients in Shipboard Electrical Systems," IEEE Trans. on Industry Applications, Vol. IA-9, No. 5, pp. 533-538, Sept/Oct 1973.

[5] Sachs, H. and Ludford, J., "Identification of Shipboard Power Line Transients: Phase I Final Report," Project No. 80-02-26, NESEA, St. Inigoes, MD, March 1980.

[6] Sachs, H. et al, "Sag/Surge and Interrupt Data Analysis on Shipboard Power Lines," Contract No. N00024-81-C-4032, NAVSEA, Washington, DC, June 1981.

## 1.4 APPROACH

The approach used in the performance of this investigation was to first reduce the data which was collected bv NESEA and then analyze this data with respect to several pertinent parameters. Over 94% of the data compiled by NESEA for the project was acquired using Dranetz Model 606-3 Power Line Disturbance Monitors; the remainder of the information was obtained using the Nicolet Model 2090-3 Digital Storage Oscilloscope. The tables and curves generated for Sections II and III and Appendix A of this report are based on the Dranetz data; a summary of the Nicolet data results accompanied by representative photographs is provided in Section 4 of this report.

Having compiled, sorted, and further reduced the data cited above, SFA analyzed this data taking into account various factors which may be characteristic to transient behavior, such as location, voltage type (120/460V), transformer proximity, mean time between transients, etc. The results of this data analysis were then tabulated, graphically-displayed, and elaborated on in the final documentation of this effort.

It should be emphasized that transient information was collected on operational shore station power lines, and that no steps were taken to tailor the lines in any way to better control the experiment. As a result, data was collected during normal operations of a facility, including line-switching events, line outages, transient suppression devices on the line, etc.

# SECTION II

# DATA ANALYSIS APPROACH

## 2.1 COLLECTION OF DATA

The monitoring procedures as well as the actual transient measurements themselves were planned and conducted by NESEA, and implemented at thirteen (13) shore facilities. The measurements were performed between May 1979 and July 1981, resulting in the collection of approximately 27,500 transients during over 134,700 instrument hours of monitoring time. Test thresholds above which a transient was recorded were either 50, 100, or in one case 200 volts. The thirteen facilities were instrumented for varying periods of time. In some cases, up to five months were monitored before it was felt a true representation of the environment was acquired, whereas only a few days were needed in other locations. All the transients recorded were naturally-occurring, i.e., no transients were simulated using transient generators, and none were attributable to lightning effects.

The data was collected at the shore facilities listed below, for which brief descriptions of some of the measurement points at each facility are also provided. Figures 2-1 through 2-7 augment these descriptions and identify most of the measurement points at each location.

### 2.1.1 NAS Key West, FL

The loads at this station consist mainly of power panels and radar power interfaces. (Figure 2-1 provides a partial depiction of the measurement points at this location. For a complete listing, see Table 2-1.)

### 2.1.2 NAS Patuxent River, MD

The only measurement point at this location was the base computer power panel. (Figure not available)

2.1.3 U.S. Naval Observatory, Washington, DC

The data for this location were collected at a single representative power panel. (Figure not available)

2.1.4 ASW Training Center, Norfolk, VA

Test locations at this site included various transformer and circuit breaker panels. (Figure 2-2)

2.1.5 Radar Site, San Juan, PR

Test points at the site included generator, antenna and electronics power panels. (Figure 2-3)

2.1.6 Fleet Training Center - Bldg. 127, Dam Neck, VA

The test locations at this site included inputs to several trainer equipment and various power panels. (Figure not available)

2.1.7 Gunfire Support Trainer, Naval Amphibious Base, Little Creek, VA

Measurements were made at only one location; loads consisted of electronic equipment and a small woodworking shop. (Figure not available)

2.1.8 2-F114 Trainer Building, NAS Oceana, VA

Measurements at this location consisted of line-to-line and line-to-ground monitoring of a trainer transformer and the main power panel. (Fig. n/a)

2.1.9 Radar Site, St. Thomas, VI

Measurement locations at this ASR-6 site included power panels, power pole air-conditioning and antenna interfaces. (Figure 2-4)

2.1.10 Anti-Personnel Intrusion Test Site, Eglin AFB, FL

Classified testing with Navy personnel and equipment was conducted at this site. (Figure 2-5)

2.1.11 FASOTRAGRUPAC (Fleet Aviation Support Organization Training Group Pacific), NAS Miramar, CA

The loads at this facility were typically Navy computers and trainers. (Figure 2-6)

2.1.12 FASOTRAGRUPAC, NAS North Island, CA

The loads here were typically computers; tests were performed at the computer inputs and at other power panels. (Figure 2-7)

2.1.13 NAVCOMSTA, Diego Garcia, Indian Ocean

Measurements were taken at six locations; loads consisted of both transmitting and receiving communications equipment. (Figure not available)

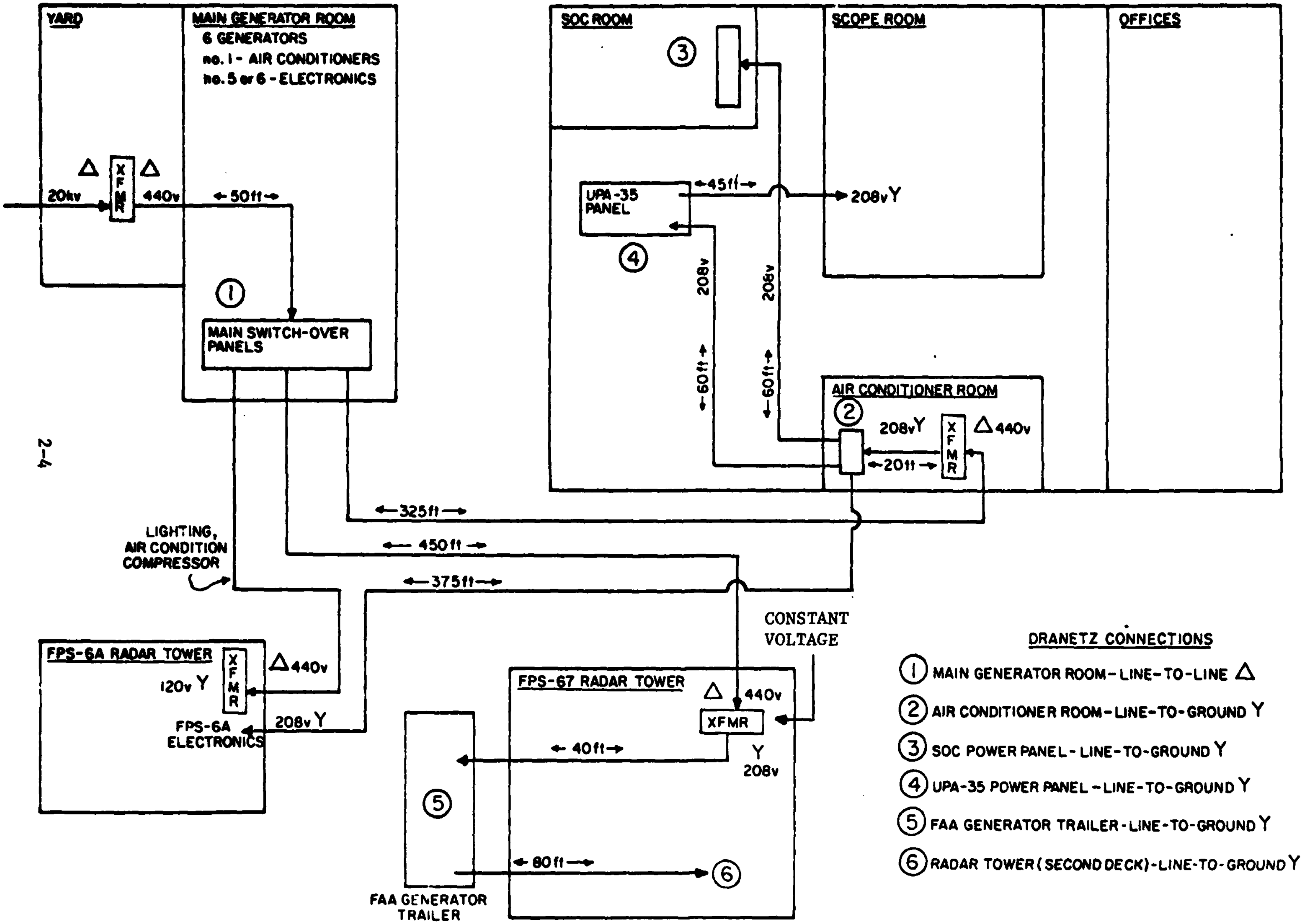



Figure 2-1. NAS Key West Measurement Locations (Partial Only)

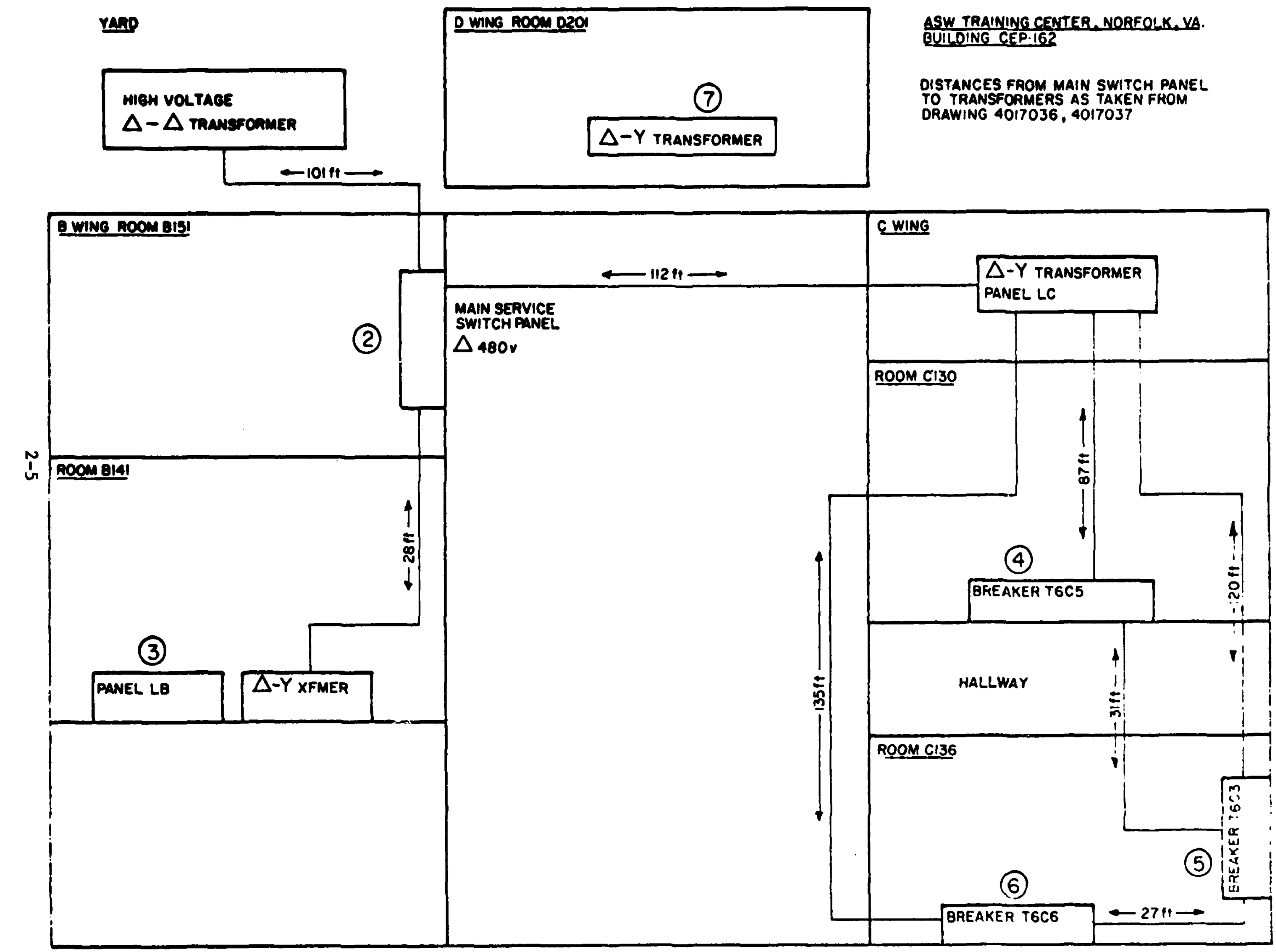
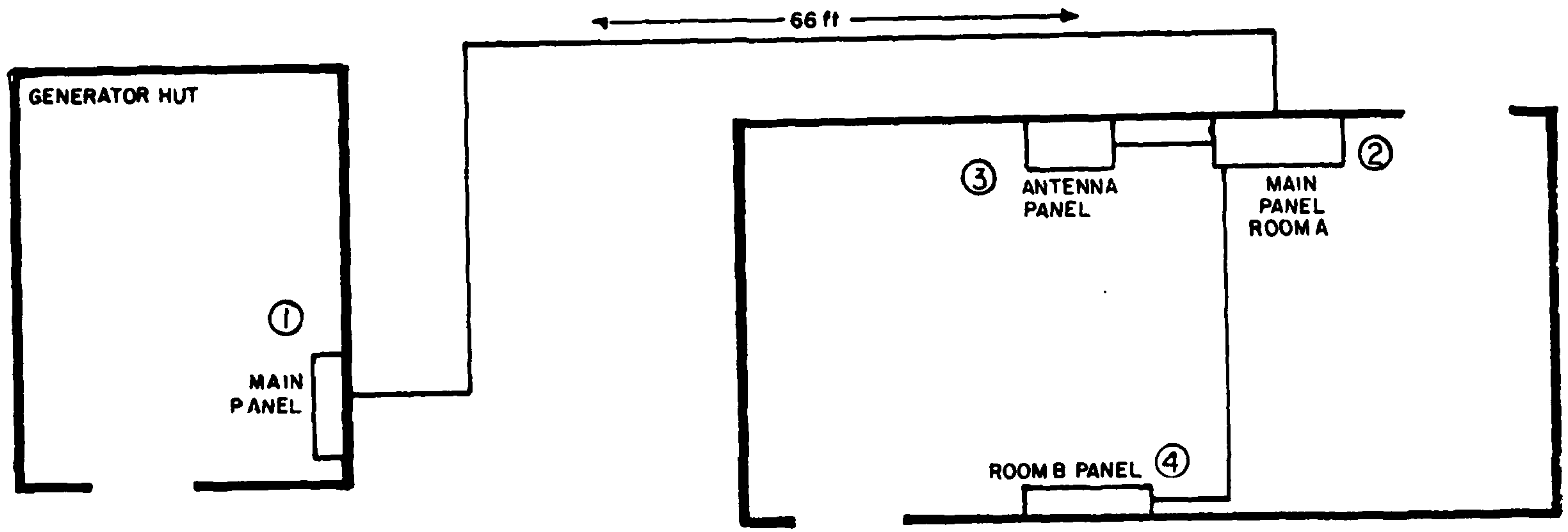



Figure 2-2. ASWTC Norfolk Measurement Locations




1. GENERATOR ROOM MAIN POWER PANEL
2. ROOM A MAIN POWER PANEL A6
3. ANTENNA POWER PANEL A3
4. ROOM B POWER PANEL A18

Figure 2-3. San Juan Radar Site Measurement Locations

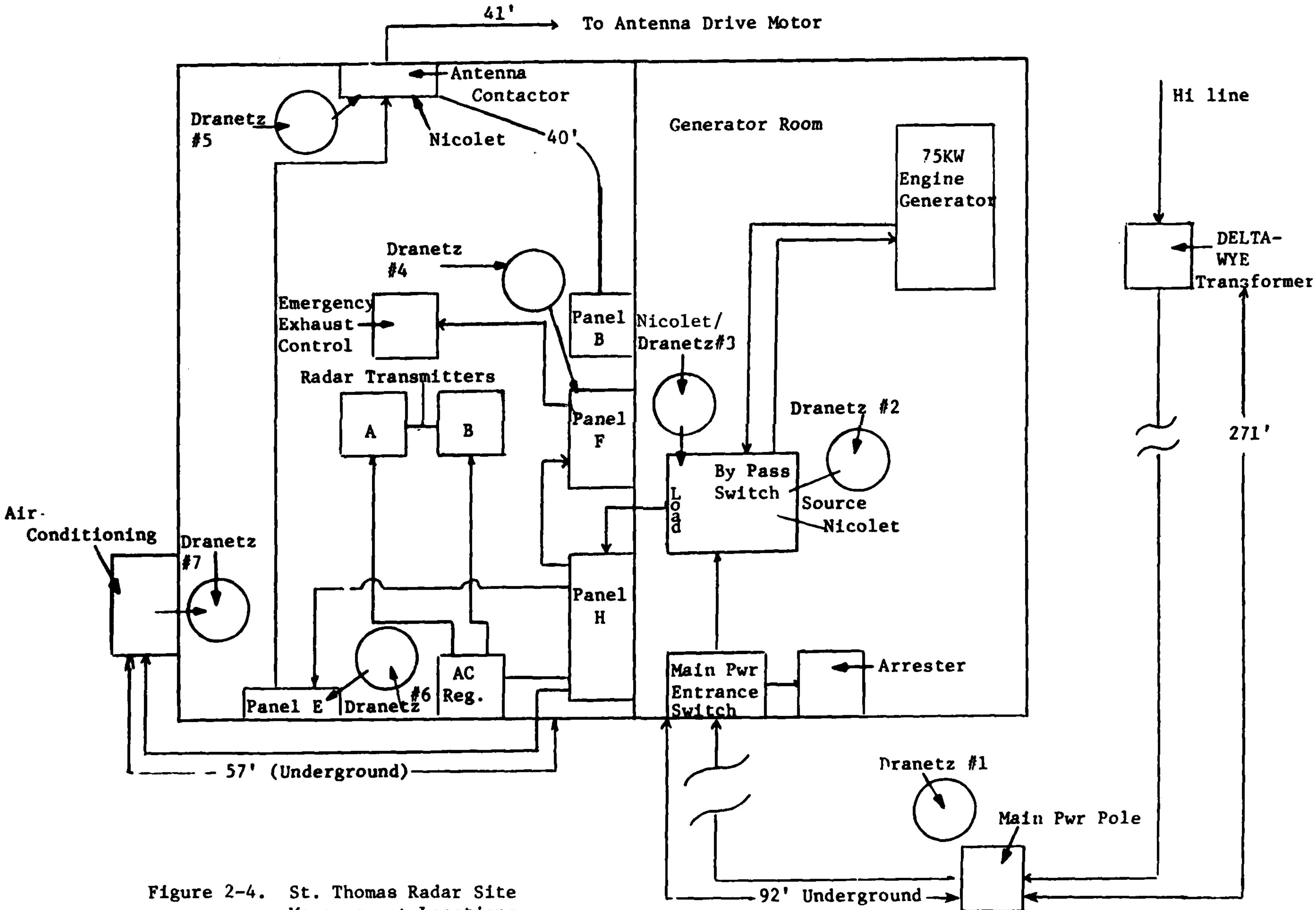



Figure 2-4. St. Thomas Radar Site Measurement Locations

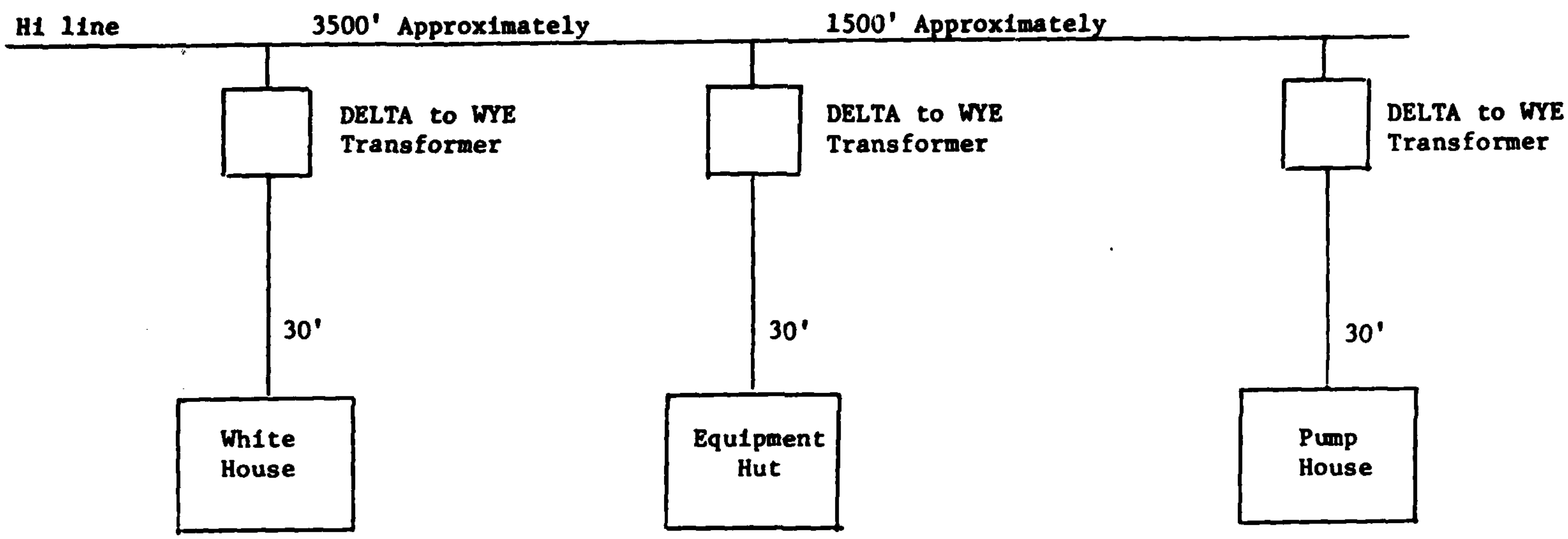



Figure 2-5. Eglin AFB Measurement Locations

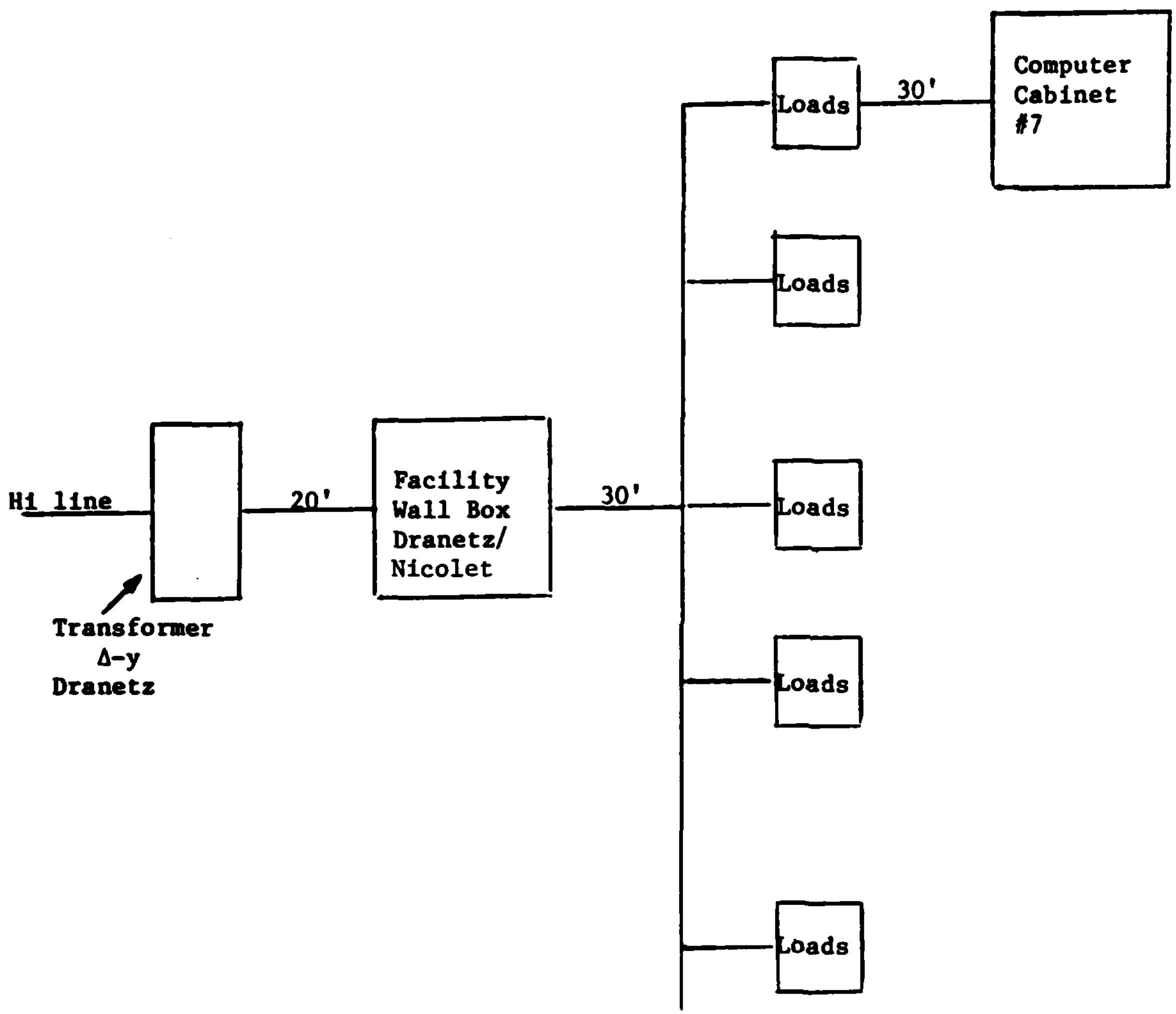



Figure 2-6. NAS Miramar Measurement Locations

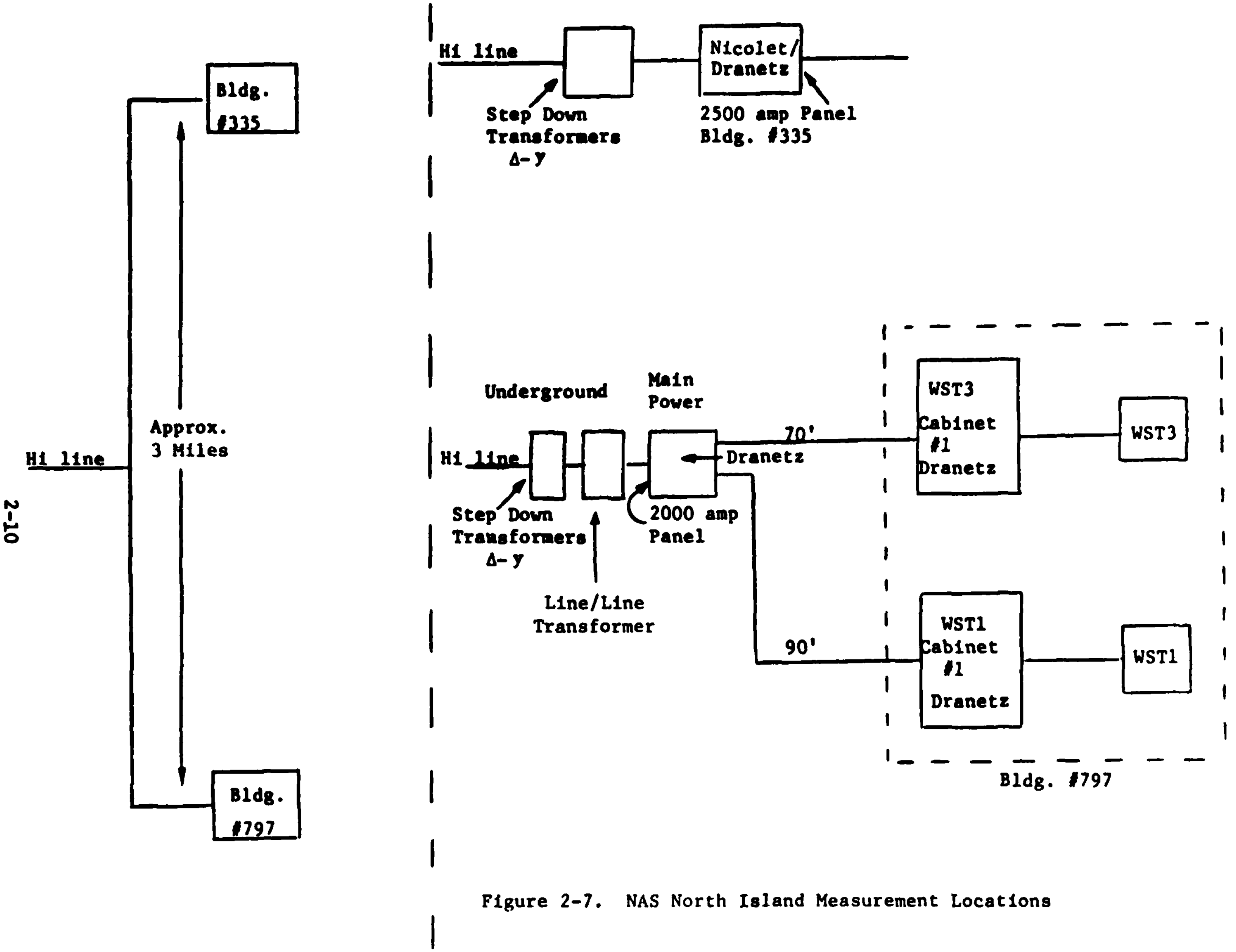



Figure 2-7. NAS North Island Measurement Locations

## 2.2 TABULATION OF DATA

The transient data collected during the test program is summarized in Tables 2-1 through 2-13, for data taken with Dranetz instrumentation, with each table corresponding to a particular test site. Similar information for data taken with Nicolet instrumentation is contained in Table 2-14. The types of information presented in the tables include the overall test period involved, the test location, distances to the line source and/or load, the voltage type, the power line frequency, the number of transients recorded, the transient amplitude distribution and the mean time between transients (MTBT).

The overall test period monitoring time is provided in instrument hours for one phase. Thus, if all three phases of a power line were monitored simultaneously (which was usually the case) for a period of one hour, the monitoring time for that period would equal three instrument hours; if only two phases were monitored, the number would be two instrument hours, and so on. In addition, the time that a test location was monitored is not necessarily continuous over the test interval but is rather the cumulative time over which the instrument was collecting data.

The threshold transient levels for the Dranetz equipments were set to 50, 100 or 200 volts, depending on (a) the primary power voltage of the line under test, and (b) the volume of lower level transients encountered. All Nicolet monitors were connected in the common mode and had 50-volt threshold levels. No transients that occurred at voltage levels below these thresholds were recorded.

At a number of sites, an almost continuous transient level existed on the power lines during intermittant intervals. These transients were generated locally by actuators, chargers and other switchable devices, and typically were encountered in the 75-200 volt peak range. As indicated above, the Dranetz thresholds were adjusted to avoid this background level.

TABLE 2-1

SUMMARY FOR

NAS KEY WEST, FL

| Test Period | Total Hours | Test Location | Approx. Distance On Power Line (Ft) | | Power Line Parameters | | TRANSIENT TEST RESULTS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | To Source | To Load | Voltage | Freq. | Numbers of Transients Measured | Mean Time Between Transients (Hrs) | AMPL Between 50V & 100V | AMPL Between 100V & 500V | AMPL Between 500V & 1000V | AMPL > 1000V |
| 9/4/80 to 10/30/80 | 3366 | Main Generator power panel | 50 | - | 460 | 60 | 246 | 13.68 | N/A | 246 | 0 | 0 |
| 9/4/80 to 10/30/80 | 3030 | SOC FPS-6A Air Cond. panel | 395 | - | 120 | 60 | 11 | 275.45 | 11 | 0 | 0 | 0 |
| 9/4/80 to 10/30/80 | 1506 | SOC Room Power Panel | 455 | - | 120 | 60 | 597 | 2.52 | 472 | 125 | 0 | 0 |
| 9/4/80 to 10/30/80 | 4032 | UPA-35 Power Panel | 455 | - | 120 | 60 | 88 | 45.82 | 56 | 32 | 0 | 0 |
| 9/4/80 to 10/30/80 | 4038 | FAA Generator Trailer | 490 | - | 120 | 60 | 251 | 16.09 | 215 | 36 | 0 | 0 |

TABLE 2-1 CONT'D

SUMMARY FOR

NAS KEY WEST, FL

| Test Period | Total Hours | Test Location | Approx. Distance On Power Line (Ft) | | Power Line Parameters | | TRANSIENT TEST RESULTS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | To Source | To Load | Voltage | Freq. | Numbers of Transients Measured | Mean Time Between Transients (Hrs) | AMPL Between 50V & 100V | AMPL Between 100V & 500V | AMPL Between 500V & 1000V | AMPL > 1000V |
| 9/4/80 to 10/30/80 | 4035 | FAA Radar Tower (FPS-67) | 570 | - | 120 | 60 | 369 | 10.65 | 328 | 41 | 0 | 0 |
| 6/23/81 to 7/22/81 | 2160 | Building 225 | - | - | 120 | 60 | 57 | 36.89 | 0 | 57 | 0 | 0 |
| 6/24/81 to 7/22/81 | 1980 | RAPCON | - | - | 120 | 60 | 3863 | .51 | 83 | 3780 | 0 | 0 |
| 6/25/81 to 7/22/81 | 1983 | GCA Radar Site* | - | - | 120 | 60 | 2473 | .80 | 25 | 2448 | 0 | 0 |
| 6/22/81 to 7/22/81 | 2163 | TACAN Site* | - | - | 120 | 60 | 625 | 3.46 | 578 | 47 | 0 | 0 |

TABLE 2-1 CONT'D

SUMMARY FOR

NAS KEY WEST, FL

| Test Period | Total Hours | Test Location | Approx. Distance On Power Line (Ft) | | Power Line Parameters | | TRANSIENT TEST RESULTS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | To Source | To Load | Voltage | Freq. | Numbers of Transients Measured | Mean Time Between Transients (Hrs) | AMPL Between 50V & 100V | AMPL Between 100V & 500V | AMPL Between 500V & 1000V | AMPL > 1000V |
| 6/23/81 to 6/24/81 to 7/15/81 to 7/21 - 7/22/81 | 703 | Remote Weather Station (Single Phase) | - | - | 120 | 60 | 56 | 12.55 | 5 | 51 | 0 | 0 |
| 6/22/81 to 7/22/81 | 2151 | Transmitter Site | - | - | 120 | 60 | 85 | 25.31 | 78 | 7 | 0 | 0 |

*Sensitivity threshold increased during monitoring period; see Section 3.5.

TABLE 2-2

SUMMARY FOR

NAS PATUXENT RIVER, MD

| Test Period | Total Hours | Test Location | Approx. Distance On Power Line (Ft) | | Power Line Parameters | | TRANSIENT TEST RESULTS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | To Source | To Load | Voltage | Freq. | Numbers of Transients Measured | Mean Time Between Transients (Hrs) | AMPL Between 50V & 100V | AMPL Between 100V & 500V | AMPL Between 500V & 1000V | AMPL > 1000V |
| 4/20/80 to 5/1/80 | 777 | T.S.D. Computer Power Panel | - | - | 120 | 60 | 1 | 777.0 | 1 | 0 | 0 | 0 |

TABLE 2-3

SUMMARY FOR

US NAVAL OBSERVATORY

WASHINGTON, DC

| Test Period | Total Hours | Test Location | Approx. Distance On Power Line (Ft) | | Power Line Parameters | | TRANSIENT TEST RESULTS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | To Source | To Load | Voltage | Freq. | Numbers of Transients Measured | Mean Time Between Transients (Hrs) | AMPL Between 50V & 100V | AMPL Between 100V & 500V | AMPL Between 500V & 1000V | AMPL > 1000V |
| 5/23/79 to 6/1/79 | 648 | Room 309 Bldg. 52 | - | - | 120 | 60 | 43 | 15.07 | 37 | 6 | 0 | 0 |

TABLE 2-4

SUMMARY FOR

ASW TRAINING CENTER

NORFOLK, VA

| Test Period | Total Hours | Test Location | Approx. Distance On Power Line (Ft) | | Power Line Parameters | | TRANSIENT TEST RESULTS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | To Source | To Load | Voltage | Freq. | Numbers of Transients Measured | Mean Time Between Transients (Hrs) | AMPL Between 50V & 100V | AMPL Between 100V & 500V | AMPL Between 500V & 1000V | AMPL > 1000V |
| 11/30/80 to 12/13/80 | 2160 | No. 1 Bldg. L-28 Room 143 | - | - | 120 | 60 | 297 | 7.30 | 254 | 43 | 0 | 0 |
| 11/13/80 to 12/12/80 | 2160 | No. 2 Bldg. CEP-162 Room 151 Main Breaker | 101 | - | 280 | 60 | 30 | 72.0 | N/A | 30 | 0 | 0 |
| 11/18/80 to 12/13/80 | 1806 | No. 3 Bldg. CEP-162 Room B141 | 129 | - | 120 | 60 | 318 | 5.68 | 308 | 10 | 0 | 0 |
| 11/17/80 to 12/13/80 | 1866 | No. 4 Bldg. CEP-162 Room C130 | 300 | - | 120 | 60 | 82 | 22.76 | 80 | 2 | 0 | 0 |

TABLE 2-4 CONT'D

SUMMARY FOR

ASW TRAINING CENTER

NORFOLK, VA

| Test Period | Total Hours | Test Location | Approx. Distance On Power Line (Ft) | | Power Line Parameters | | TRANSIENT TEST RESULTS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | To Source | To Load | Voltage | Freq. | Numbers of Transients Measured | Mean Time Between Transients (Hrs) | AMPL Between 50V & 100V | AMPL Between 100V & 500V | AMPL Between 500V & 1000V | AMPL > 1000V |
| 11/13/80 to 12/13/80 | 1878 | No. 5 Bldg. CEP-162 Room C136 Breaker T6C3 | 333 | - | 120 | 60 | 115 | 16.33 | 94 | 21 | 0 | 0 |
| 11/17/80 to 12/13/80 | 1866 | No. 6 Bldg. CEP-162 Room C136 Breaker T6C6 | 348 | - | 120 | 60 | 86 | 21.70 | 69 | 17 | 0 | 0 |
| 11/14/80 to 12/14/80 | 2145 | No. 7 Bldg. CEP-162 Room D201 | - | - | 120 | 60 | 51 | 42.06 | 22 | 29 | 0 | 0 |

TABLE 2-5

SUMMARY FOR

RADAR SITE

SAN JUAN, PR

| Test Period | Total Hours | Test Location | Approx. Distance On Power Line (Ft) | | Power Line Parameters | | TRANSIENT TEST RESULTS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | To Source | To Load | Voltage | Freq. | Numbers of Transients Measured | Mean Time Between Transients (Hrs) | AMPL Between 50V & 100V | AMPL Between 100V & 500V | AMPL Between 500V & 1000V | AMPL > 1000V |
| 1/8/81 to 1/26/81 | 1290 | No. 1 Generator Room Main Power Panel | - | - | 120 | 60 | 2176 | .59 | 2148 | 28 | 0 | 0 |
| 1/7/81 to 1/26/81 | 1356 | No. 2 Room A Main Power Panel | 66 | - | 120 | 60 | 56 | 24.21 | 29 | 27 | 0 | 0 |
| 1/7/81 to 1/26/81 | 1368 | No. 3 Antenna Power Panel | - | - | 120 | 60 | 183 | 7.48 | 151 | 32 | 0 | 0 |
| 1/7/81 to 1/26/81 | 1353 | No. 4 Electronics Room B Power Panel A 14 | - | - | 120 | 60 | 1433 | .94 | 1398 | 35 | 0 | 0 |

TABLE 2-6

SUMMARY FOR

FLEET TRAINING CENTER, BLDG. 127

DAM NECK, VA

| Test Period | Total Hours | Test Location | Approx. Distance On Power Line (Ft) | | Power Line Parameters | | TRANSIENT TEST RESULTS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | To Source | To Load | Voltage | Freq. | Numbers of Transients Measured | Mean Time Between Transients (Hrs) | AMPL Between 50V & 100V | AMPL Between 100V & 500V | AMPL Between 500V & 1000V | AMPL > 1000V |
| 5/5/81 to 6/10/81 | 2472 | Room 02A Panel 5A03 Sonar Team Trainer | - | - | 120 | 60 | 884 | 2.80 | 783 | 101 | 0 | 0 |
| 5/7/81 to 6/10/81 | 2408 | Room 40 RADNAV Trainer | - | - | 120 | 60 | 81 | 29.73 | 69 | 12 | 0 | 0 |
| 5/5/81 to 6/10/81 | 2580 | Room 43 Panel 43-3 FFG-7 | - | - | 120 | 60 | 248 | 10.40 | 200 | 48 | 0 | 0 |
| 5/15/81 to 6/10/81 | 2583 | Room 114 Panel EP-2 Computer Complex | - | - | 120 | 60 | 216 | 11.96 | 193 | 23 | 0 | 0 |

TABLE 2-6 CONT'D

SUMMARY FOR

FLEET TRAINING CENTER, BLDG. 127

DAM NECK, VA

| Test Period | Total Hours | Test Location | Approx. Distance On Power Line (Ft) | | Power Line Parameters | | TRANSIENT TEST RESULTS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | To Source | To Load | Voltage | Freq. | Numbers of Transients Measured | Mean Time Between Transients (Hrs) | AMPL Between 50V & 100V | AMPL Between 100V & 500V | AMPL Between 500V & 1000V | AMPL > 1000V |
| 5/7/81 to 5/19/81 | 858 | Room 136 Panel 24 FG-6 (Galley Hallway) | - | - | 120 | 60 | 0 | N/A | 0 | 0 | 0 | 0 |
| 5/5/81 to 6/10/81 | 642 | Room 215 Panel EP-15 | - | - | 120 | 60 | 0 | N/A | 0 | 0 | 0 | 0 |
| 5/7/81 to 6/10/81 | 816 | Room 43 Sensor Simulation Subsystem | - | - | 120 | 60 | 25 | 32.64 | 21 | 4 | 0 | 0 |

TABLE 2-7

SUMMARY FOR

NAVAL AMPHIBI.. IS BASE

LITTLE CREEK, VA

| Test Period | Total Hours | Test Location | Approx. Distance On Power Line (Ft) | | Power Line Parameters | | TRANSIENT TEST RESULTS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | To Source | To Load | Voltage | Freq. | Numbers of Transients Measured | Mean Time Between Transients (Hrs) | AMPL Between 50V & 100V | AMPL Between 100V & 500V | AMPL Between 500V & 1000V | AMPL > 1000V |
| 5/14/81 to 6/10/81 | 1929 | Main Bldg. Power Input Panel | - | - | 120 | 60 | 12 | 160.75 | 0 | 12 | 0 | 0 |

TABLE 2-8

SUMMARY FOR 2-F114 TRAINER BUILDING

NAS OCEANA, VA

| Test Period | Total Hours | Test Location | Approx. Distance On Power Line (Ft) | | Power Line Parameters | | TRANSIENT TEST RESULTS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | To Source | To Load | Voltage | Freq. | Numbers of Transients Measured | Mean Time Between Transients (Hrs) | AMPL Between 50V & 100V | AMPL Between 100V & 500V | AMPL Between 500V & 1000V | AMPL > 1000V |
| 5/16/81 to 6/10/81 | 2505 | Transformer Line to Line | - | - | 460 | 60 | 97 | 25.82 | N/A | 89 | 7 | 1 |
| 5/19/81 to 6/10/81 | 1575 | Transformer Line to Ground | - | - | 460 | 60 | 199 | 7.91 | N/A | 196 | 3 | 0 |
| 5/5/81 to 6/9/81 | 2097 | Transformer Main Power Panel | - | - | 120 | 60 | 330 | 6.35 | 198 | 127 | 5 | 0 |

TABLE 2-9

SUMMARY FOR

RADAR SITE

ST. THOMAS, VIRGIN ISLANDS

| Test Period | Total Hours | Test Location | Approx. Distance On Power Line (Ft) | | Power Line Parameters | | TRANSIENT TEST RESULTS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | To Source | To Load | Voltage | Freq. | Numbers of Transients Measured | Mean Time Between Transients (Hrs) | AMPL Between 50V & 100V | AMPL Between 100V & 500V | AMPL Between 500V & 1000V | AMPL > 1000V |
| 2/12/80 to 3/14/80 | 16209 | Panel F | - | - | 120 | 60 | 1070 | 15.15 | 1070 | 0 | 0 | 0 |
| 2/12/80 to 3/13/80 | 2166 | Load | - | - | 120 | 60 | 243 | 7.13 | 243 | 0 | 0 | 0 |
| 2/12/80 to 3/13/80 | 2166 | Source | - | - | 120 | 60 | 3083 | .70 | 3083 | 0 | 0 | 0 |
| 2/15/80 to 3/13/80 | 1974 | Air Conditioning | 57 | 57 | 120 | 60 | 52 | 37.96 | 48 | 4 | 0 | 0 |

TABLE 2-9 CONT'D

SUMMARY FOR

*RADAR SITE*

ST. THOMAS, VIRGIN ISLANDS

| Test Period | Total Hours | Test Location | Approx. Distance On Power Line (Ft) | | Power Line Parameters | | TRANSIENT TEST RESULTS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | To Source | To Load | Voltage | Freq. | Numbers of Transients Measured | Mean Time Between Transients (Hrs) | AMPL Between 50V & 100V | AMPL Between 100V & 500V | AMPL Between 500V & 1000V | AMPL > 1000V |
| 2/13/80 to 3/13/80 | 1974 | Panel E | - | - | 120 | 60 | 93 | 21.23 | 87 | 6 | 0 | 0 |
| 2/14/80 to 3/14/80 | 2031 | Power Pole | 271 | 92 | 120 | 60 | 110 | 18.46 | 102 | 8 | 0 | 0 |
| 2/18/80 to 3/14/80 | 1746 | Antenna | 40 | 41 | 120 | 60 | 232 | 7.53 | 137 | 86 | 9 | 0 |

TABLE 2-10

SUMMARY FOR

ANTI-PERSONNEL INTRUSION TEST SITE

EGLIN AFB, FL

| Test Period | Total Hours | Test Location | Approx. Distance On Power Line (Ft) | | Power Line Parameters | | TRANSIENT TEST RESULTS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | To Source | To Load | Voltage | Freq. | Numbers of Transients Measured | Mean Time Between Transients (Hrs) | AMPL Between 50V & 100V | AMPL Between 100V & 500V | AMPL Between 500V & 1000V | AMPL > 1000V |
| 11/16/79 to 1/18/80 | 4533 | Equipment Hut Power Pole | 30 | - | 208 | 60 | 2356 | 1.92 | N/A | 2356 | 0 | 0 |
| 11/16/79 to 1/18/80 | 4533 | Pump House | 30 | - | 208 | 60 | 40 | 113.33 | N/A | 40 | 0 | 0 |
| 11/16/79 to 1/18/80 | 1860 | White House Bldg. E119 | 30 | - | 120 | 60 | 2939 | .63 | 1344 | 1595 | 0 | 0 |

TABLE 2-11

SUMMARY FOR

FASOTRAGRUPAC

NAS MIRAMAR, CA

| Test Period | Total Hours | Test Location | Approx. Distance On Power Line (Ft) | | Power Line Parameters | | TRANSIENT TEST RESULTS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | To Source | To Load | Voltage | Freq. | Numbers of Transients Measured | Mean Time Between Transients (Hrs) | AMPL Between 50V & 100V | AMPL Between 100V & 500V | AMPL Between 500V & 1000V | AMPL > 1000V |
| 10/1/79 to 10/25/79 | 1641 | Facility Wall Box | 20 | 30 | 120 | 60 | 227 | 7.23 | 100 | 127 | 0 | 0 |
| 10/2/79 to 10/25/79 | 1722 | Main Power Panel | 30 | 30 | 120 | 60 | 13 | 132.46 | 0 | 13 | 0 | 0 |
| 10/1/79 to 10/25/79 | 1722 | Computer Cabinet #7 | 30 | 30 | 120 | 60 | 348 | 4.95 | 0 | 348 | 0 | 0 |

TABLE 2-12

SUMMARY FOR

FASOTRAGRUPAC

NAS NORTH ISLAND, CA

| Test Period | Total Hours | Test Location | Approx. Distance On Power Line (Ft) | | Power Line Parameters | | TRANSIENT TEST RESULTS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | To Source | To Load | Voltage | Freq. | Numbers of Transients Measured | Mean Time Between Transients (Hrs) | AMPL Between 50V & 100V | AMPL Between 100V & 500V | AMPL Between 500V & 1000V | AMPL > 1000V |
| 11/27/79 to 1/7/80 | 603 | WST-1 Cabinet 1 | 70 | - | 208 | 60 | 46 | 13.11 | N/A | 46 | 0 | 0 |
| 11/28/79 to 1/7/80 | 2897 | WST-3 Cabinet 1 | 90 | 50 | 120 | 60 | 234 | 12.38 | 142 | 92 | 0 | 0 |
| 11/29/79 to 1/7/80 | 2808 | 2500 AMP Panel | - | 20-50 | 120 | 60 | 228 | 13.32 | 154 | 74 | 0 | 0 |
| 11/27/79 to 1/7/80 | 2346 | 2000 AMP Panel | 27 | 70-90 | 120 | 60 | 141 | 16.64 | 82 | 59 | 0 | 0 |

TABLE 2-13

SUMMARY FOR

NAVCOMSTA, DIEGO GARCIA,

INDIAN OCEAN

| Test Period | Total Hours | Test Location | Approx. Distance On Power Line (Ft) | | Power Line Parameters | | TRANSIENT TEST RESULTS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | To Source | To Load | Voltage | Freq. | Numbers of Transients Measured | Mean Time between Transients | AMPL Between 50V & 100V | AMPL Between 100V & 500V | Between 500V & 1000V | AMPL > 1000V |
| 4/2/81 to 4/8/81 | 423 | "R" Site Tech Control VCFT Primary Power Panel | - | - | 120 | 60 | 12 | 35.25 | 12 | 0 | 0 | 0 |
| 4/2/81 to 4/8/81 | 420 | "R" Site -SATCOM- 480 VAC Power Distribution Panel and DCSS Van Tech Power | - | - | 120 | 60 | 26 | 16.15 | 26 | 0 | 0 | 0 |
| 4/8/81 to 4/15/81 | 501 | "R" Site Message Center - SPT Paper Tape Punch (PTP) Primary Power Panel | - | - | 120 | 60 | 3 | 167.00 | 3 | 0 | 0 | 0 |
| 4/3/81 to 4/8/81 | 46 | "T" Site AN/FRT-84- Hot Side I-Box Power-on-Light | - | - | 120 | 60 | 0 | 0 | 0 | 0 | 0 | 0 |

TABLE 2-13 CONT'D

SUMMARY FOR

NAVCOMSTA, DIEGO GARCIA,

INDIAN OCEAN

| Test Period | Total Hours | Test Location | Approx. Distance On Power Line (Ft) | | Power Line Parameters | | TRANSIENT TEST RESULTS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | To Source | To Load | Voltage | Freq. | Numbers of Transients Measured | Mean Time between Transients | AMPL Between 50V & 100V | AMPL Between 100V & 500V | Between 500V & 1000V | AMPL > 1000V |
| 4/3/81 to 4/8/81 | 375 | "T" Site MINI-AS-COM Power Panel | - | - | 120 | 60 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4/3/81 to 4/8/81 | 122 | AN/FRT-85 Power Line Terminals | - | - | 280 | 60 | 32 | 8.75 | 23 | 9 | 0 | 0 |

TABLE 2-14

SUMMARY FOR NICOLET MONITORING LOCATIONS

| Test Location | Monitoring Period (Hrs) | AC Voltage (v) | No. of Transients Recorded | Mean Time Between Transients (Hrs) | AMPL Between 50V & 100V | AMPL Between 100V & 500V | AMPL Between 500 & 1000V | AMPL > 1000V |
|---|---|---|---|---|---|---|---|---|
| Radar Site, St. Thomas | | | | | | | | |
| - Source | 168 | 120 | 35 | 4.08 | 13 | 15 | 3 | 4 |
| - Load | 24 | 120 | 7 | 3.43 | 7 | 0 | 0 | 0 |
| - Antenna | 288 | 120 | 55 | 5.24 | 0 | 6 | 15 | 34 |
| NAS Miramar | | | | | | | | |
| - Facility Wall Box | 216 | 120 | 13 | 16.62 | 13 | 0 | 0 | 0 |
| NAS North Island | | | | | | | | |
| - 2500 Amp. Panel | 914 | 120 | 14 | 65.29 | 3 | 11 | 0 | 0 |

TABLE 2-14 CONT'D

**SUMMARY FOR NICOLET MONITORING LOCATIONS**

| Test Location | Monitoring Period (Hrs) | AC Voltage (v) | No. of Transients Recorded | Mean Time Between Transients (Hrs) | AMPL Between 50V & 100V | AMPL Between 100V & 500V | AMPL Between 500V & 1000V | AMPL > 1000V |
|---|---|---|---|---|---|---|---|---|
| NAS Key West, FL | | | | | | | | |
| - SOC Room Power Panel | 1010 | 120 | 35 | 11.88 | 85 | 0 | 0 | 0 |
| - FAA Radar Tower (FPS-67) | 1345 | 120 | 10 | 134.5 | 9 | 1 | 0 | 0 |
| - Main Generator Room | 1122 | 460 | 10 | 112.2 | 10 | 0 | 0 | 0 |
| - TACAN Site | 721 | 120 | 13 | 55.46 | 0 | 13 | 0 | 0 |
| ASW Training Center Norfolk, VA | | | | | | | | |
| - Bldg. L-28 Room 43 | 720 | 120 | 14 | 51.43 | 11 | 3 | 0 | 0 |
| Radar Site San Juan Puerto Rico | | | | | | | | |
| - Antenna Power Panel | 456 | 120 | 3 | 152.0 | 3 | 0 | 0 | 0 |
| - Generator Room Main Power Panel | 430 | 120 | 18 | 23.89 | 8 | 10 | 0 | 0 |

TABLE 2-14 CONT'D

**SUMMARY FOR NICOLET MONITORING LOCATIONS**

| Test Location | Monitoring Period (Hrs) | AC Voltage (v) | No. of Transients Recorded | Mean Time Between Transients (Hrs) | AMPL Between 50V & 100V | AMPL Between 100V & 500V | AMPL Between 500V & 1000V | AMPL > 1000V |
|---|---|---|---|---|---|---|---|---|
| NAVCOMSTA Diego Garcia Indian Ocean | | | | | | | | |
| - B-10-T | 122 | 120 | 20 | 6.1 | 9 | 11 | 0 | 0 |

The sites at which this effect occurred are listed below. In addition, the rates of the low-level transients are provided, as well as the transient rate that occurred once the test threshold was raised.

| SITE | RATE OF LOW-LEVEL TRANSIENT BACKGROUND (/hr) | RATE OF TRANSIENTS WITH THRESHOLD ABOVE LOW-LEVEL TRANSIENTS (/hr) |
|---|---|---|
| NAS, Key West | | |
| SOC Room Power Panel | 112.89 | .4 |
| RAPCON | 64.33 | 1.96 |
| GCA Radar Site | 198.99 | 1.25 |
| Remote Weather Station | 21.13 | .08 |
| ASWTC, Norfolk, VA | | |
| No. 3 Bldg. CEP-162, Room B141 | 825.88 | .18 |
| Radar Site, San Juan, PR | | |
| No. 1, Generator Room Main Power Panel | 4270.7 | 1.69 |
| No. 4 Electronics Room B Power Panel A14 | 384.94 | 1.06 |
| Fleet Training Center, Bldg. 127 Dam Neck, VA | | |
| Room 02A Panel 5A03 Sonar Team Trainer | 201.16 | .4 |

The numbers of transients recorded in the tables for each test location are the sum of the transients which occurred on each of the three phases. Correspondingly, all analysis and statistical manipulation that was performed for this effort was based on the accumulated data of all three power line phases. The transient amplitude distribution columns in the tables are grouped by peak amplitude levels that were recorded after filtering to reject the power line frequency signal. No measurements were made of transients in ranges designated by N/A.

## 2.3 GRAPHICAL DISPLAY OF DRANETZ DATA PROBABILITY

The Dranetz Model 606-3 Power Line Disturbance Analyzers were used to continuously monitor the transient situation on up to three phases of the lines to which they were connected. The instruments were connected either line-to-neutral (120V) or line-to-line (208V) and were set to record all transients which exceeded a set threshold. The threshold for 120 volt connections was either 50 volts with the recorded readings quantized in four volt increments above the threshold, 100 volts with quantization increments of 8 volts, or 200 volts with 16-volt quantization levels. The line-to-line or 208 volt threshold was set to 100 volts. In a few instances when several transients occurred within the same time period, only the magnitude of the largest transient was recorded by the analyzer, along with the total number of transients exceeding the threshold during that time increment.

The number of transients that occurred at each voltage level for a particular line was totaled and a cumulative distribution developed. The distributions represent the percentage of the transients recorded which exceed a voltage level and are different from the usual cumulative distributions which are associated with probability functions. The usual cumulative distribution function $F(V)$ is the probability that a voltage $v$ is less than or equal to a given voltage level, ($F(V) = P[v \leq V]$), whereas the cumulative distribution developed herein, $F_c(V)$ is the probability that a voltage $v$ is greater than or equal to the given voltage level ($F_c(V) = P[v \geq V]$). The cumulative distributions are related by $F_c(V) = 1-F(V)$. Because most of the occurrences of transients were at the lower voltage levels, this complement of the usual cumulative distribution function provides a clearer graphical display of the transient distribution.

The complementary cumulative distribution function, $F_c(V)$, was plotted on different graphs for several locations to determine the type of graph (linear vs. linear, linear vs. log, normal versus linear, etc.) most suitable for graphical representation and extrapolation. It was determined empirically that the use of log-log paper resulted in a linear characterization of transient behavior probability for most sites. In only a few cases were piecewise linear or quadratic curves required.

Figures depicting transient amplitude complementary distribution functions for each of the monitoring locations at the various test sites are provided in this report as Appendix A. Further summaries of Dranetz data will be found in the next section of this report.

## 2.4 PRESENTATION OF NICOLET DATA

Nicolet data was collected at all shore facilities except the U. S. Naval Observatory and NAS Patuxent River. Only 297 transient recordings were obtained over 7,536 hours of monitoring. Because of the nature of that data an analysis and discussion of results separate from that for the Dranetz data was considered appropriate. The Nicolet information was evaluated with emphasis on pulse amplitude, duration, energy, dc effects, etc. This evaluation will be found in Section IV of this report.

## SECTION III

## DRANETZ DATA SUMMARIES

### 3.1 SITE STATISTICAL RESULTS

Table 3-1 provides a summary of shore facility transients as recorded by Dranetz instrumentation. Entries in the table are differentiated by site and voltage type. Information provided in the table includes instrument monitoring time, number of transients recorded, mean time between transients, transient amplitude distribution and the maximum transient amplitude recorded at each site.

#### 3.1.1 NAS Key West, FL

At this site, measurements were made on 120 volt lines during two separate visits, and on 460 volt lines during one visit. There were over 31,000 monitoring hours recorded (120V, 460V lines combined), the longest measurement period for any of the sites. For the combined 120 volt line monitoring points at this site, there was a comparatively short mean time between transients (MTBT), 3.3 hours. At only two other sites were there MTBT's that were shorter for 120 volt lines: these were San Juan and Eglin AFB (see Table 3-1). At the 460 volt monitoring location, a relatively long MTBT of 13.7 hours resulted. There were 8,475 transients recorded at Key West on 120 volt lines, also a high for all sites: 78% occurred between 100 and 500 volts and the remainder occurred between threshold (50 V) and 100 volts. At the 460 volt measurement point, all of the recorded transients occurred with levels between 100 and 500 volts.

The most active location transient-wise at the Key West site was the 120 volt line RAPCON location, both from a maximum number of recorded transients standpoint as well as from a shortest mean time between transients (MTBT)

TABLE 3-1

COMPOSITE SITE SUMMARY, DRANETZ DATA

| TEST SITE | Power Line Parameters | | Total Hours | TRANSIENT TEST RESULTS | | | | | | Maximum AMPL Level Recorded |
|---|---|---|---|---|---|---|---|---|---|---|
| | Voltage | Freq. | | Numbers of Transients Measured | Mean Time Between Transients (Hrs) | AMPL Between 50V & 100V | AMPL Between 100V & 500V | AMPL Between 500V & 1000V | AMPL > 1000V | |
| NAS Key West, FL | 120 | 60 | 27781 | 8475 | 3.28 | 1851 | 6624 | 0 | 0 | 352 |
| NAS Key West, FL | 460 | 60 | 3366 | 246 | 13.68 | N/A | 246 | 0 | 0 | 496 |
| NAS Patuxent River, MD | 120 | 60 | 777 | 1 | 777.00 | 1 | 0 | 0 | 0 | 60 |
| U.S. Naval Observatory Washington, D. C. | 120 | 60 | 648 | 43 | 15.07 | 37 | 6 | 0 | 0 | 124 |
| ASW Training Center Norfolk, VA | 120 | 60 | 11721 | 949 | 12.35 | 827 | 122 | 0 | 0 | 316 |
| ASW Training Center Norfolk, VA | 280 | 60 | 2160 | 30 | 72.00 | N/A | 30 | 0 | 0 | 248 |
| Radar Site, San Juan, PR | 120 | 60 | 5367 | 3848 | 1.39 | 3726 | 122 | 0 | 0 | 304 |
| Fleet Training Center, Bldg. 127, Dam Neck, VA | 120 | 60 | 12359 | 1454 | 8.50 | 1266 | 188 | 0 | 0 | 356 |
| Navy Amphibious Base Little Creek, VA | 120 | 60 | 1929 | 12 | 160.75 | 0 | 12 | 0 | 0 | 216 |
| NAS Oceana, VA | 120 | 60 | 2097 | 330 | 6.35 | 198 | 127 | 5 | 0 | 872 |

TABLE 3-1 CONT'D

COMPOSITE SITE SUMMARY, DRANETZ DATA

| TEST SITE | Power Line Parameters | | Total Hours | TRANSIENT TEST RESULTS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Voltage | Freq. | | Numbers of Transients Measured | Mean Time Between Transients (Hrs) | AMPL Between 50V & 100V | AMPL Between 100V & 500V | AMPL Between 500V & 1000V | AMPL > 1000V | Maximum AMPL Level Recorded |
| NAS Oceana, VA | 460 | 60 | 4080 | 296 | 13.78 | N/A | 285 | 10 | 1 | 1184 |
| Radar Site, St. Thomas, Virgin Islands | 120 | 60 | 28266 | 4883 | 5.79 | 4770 | 104 | 9 | 0 | 840 |
| Anti-Personnel Intrusion Test Site, Eglin AFB, FL | 208 | 60 | 9066 | 2396 | 3.78 | N/A | 2396 | 0 | 0 | 216 |
| Anti-Personnel Intrusion Test Site, Eglin AFB, FL | 120 | 60 | 1860 | 2939 | .63 | 1344 | 1595 | 0 | 0 | 280 |
| FASOTRAGRUPAC, NAS Miramar, CA | 120 | 60 | 5085 | 588 | 8.65 | 100 | 488 | 0 | 0 | 236 |
| FASOTRAGRUPAC, NAS North Island, CA | 208 | 60 | 603 | 46 | 13.11 | N/A | 46 | 0 | 0 | 296 |
| FASOTRAGRUPAC, NAS North Island, CA | 120 | 60 | 8051 | 603 | 9.46 | 378 | 225 | 0 | 0 | 268 |
| NAVCOMSTA, Diego Garcia, Indian Ocean | 120 | 60 | 1765 | 41 | 43.05 | 41 | 0 | 0 | 0 | 88 |
| NAVCOMSTA, Diego Garcia, Indian Ocean | 280 | 60 | 122 | 32 | 3.81 | 23 | 9 | 0 | 0 | 404 |

point-of-view. (Refer to Table 2-1) There were 3863 transients recorded over a period of 1980 hours at this location yielding an MTBT of 0.5 hours, the shortest MTBT of all site locations. Although none of the transients recorded at this location exceeded 500 volts, 98% of them occurred with levels between 100 and 500 volts. The lowest number of transients and longest MTBT on the 120 volt line locations at this site occurred at the Air Conditioning Room: only eleven transients were recorded here with a calculated MTBT of 275.5 hours.

The highest transient recorded on 120 volt lines at this site was 352 volts, measured at the UPA-35 Power Panel. On 460 volt lines the maximum level recorded was 496 volts at the Main Generator Power Panel Location monitoring point.

3.1.2 NAS Patuxent River, MD

Only a single 120 volt power panel was monitored at this site. During the 777 hours recorded at this location, only one transient exceeded the voltage level threshold of 50 volts; it was measured at 60 volts, as shown in Table 3-1. Even considering the relatively short duration of the monitoring period, this site possessed the quietest transient environment of all sites considered.

3.1.3 U.S. Naval Observatory, Washington DC

As at NAS Patuxent River, only a single 120 volt location was monitored at this site. There was no correlation between the transients noted and any suspected source. As shown in Table 3-1, during the relatively short 648 hour monitoring period for this site, 43 transients occurred. Only 6 (14%) of these transients exceed a 100 volt level, with the highest transient measured at 124 volts. The MTBT was 15.1 hours.

### 3.1.4 ASWTC Norfolk, VA

Both 120 volt and 280 volt power lines were monitored at this site. As noted in Table 3-1, 11,721 instrument hours were recorded on 120 volt lines, and 2160 hours were recorded at the 280 volt line monitoring point. On 120 volt lines, 949 transients were recorded with an MTBT of 12.4 hours. Of these, 87.1% occurred between 50 and 100 volts and the remainder occurred between 100 and 500 volts. All 30 transients recorded at the 280 volt Main Breaker (see Table 2-4) occurred between 100 and 500 volts with a long MTBT of 72 hours.

The 120 volt line location at Norfolk where the highest number of transients occurred, as well as the shortest MTBT, was Building CEP-162, Room B141. There were 318 transients recorded here, having an MTBT of 5.7 hours. Of these, 97% occurred at levels between threshold (50V) and 100 volts. The lowest number of transients and longest MTBT both occurred at Building CEP-162, Room D201; a total of 51 transients were recorded with an MTBT of 42.1 hours. Nevertheless, it was also at this location that the highest 120 volt line transient was registered, 316 volts.

At Building CEP-162, Room 151, the 280 volt line circuit breaker, 30 transients were recorded between 100 and 500 volts with an MTBT of 72.0 hours. The peak transient occurring at this location was 248 volts.

### 3.1.5 Radar Site, San Juan, PR

The locations monitored at this site were all located on 120 volt lines. During the 5367 hours of instrument monitoring time cited in Table 3-1, 3848 transients were recorded with a composite MTBT of only 1.4 hours. 97% of these registered between threshold and 100 volts; the remainder were measured between 100 and 500 volts.

The most active location at this site was Loc. No. 1, the Generator Room Main Power Panel, where the maximum number of transients were measured as well as the shortest MTBT. (See Table 2-5.) During 1290 hours of monitoring, 2176 transients occurred with an extremely short MTBT of 0.59 hours. 98.7% of these occurred with peaks between 50 and 100 volts, with the remainder recorded between 100 and 500 volts. The lowest number of transients, 56, and longest MTBT, 24.2 hours, were recorded at the Room A Main Power Panel.

The highest transient at this site was recorded at Location No. 4, Electronics Room B Power Panel A14, with a value of 304 volts.

### 3.1.6 Fleet Training Center, Dam Neck, VA

Ac measurement points at this site were restricted to 120 volt lines. During the 12,359 hours of monitoring at this site, there were 1454 transients recorded with a composite MTBT of 8.5 hours, as shown in Table 3-1. Of these, 87% occurred between threshold (50V) and 100 volts, with the remainder occurring between 100 and 500 volts.

The highest number of transients, shortest MTBT, and highest transient peak amplitude for this site were all three recorded at Room 02A, Panel 5A03, Sonar Team Trainer. (See Table 2-6.) There were 884 transients, recorded here with an MTBT of 2.8 hours, the highest of which occurred with a peak amplitude of 356 volts.

There were also two locations at this site where no transients occurred at all over a combined monitoring period of 1500 hours. These locations were at Rm. 136, Panel EP-2 and Rm. 136, Panel 24 FG-6.

### 3.1.7 Naval Amphibious Base, Little Creek, VA

At the solitary 120 volt line power panel monitored at this location (See Tables 2-7 and 3-1), 12 transients between 100 and 500 volts were recorded over a 1929 hour period yielding a long MTBT of 160.8 hours. The peak transient value recorded was 216 volts.

### 3.1.8 NAS Oceana, VA

One 120 volt line and two 460 volt line locations were monitored at this site. There was a combined (120V, 460V) monitoring time at this site of 6177 instrument hours. At the 120 volt location (Main Power Panel), 330 transients were recorded with an MTBT of 6.4 hours. Of these, 60% were recorded between 50 and 100 volts, 38% were logged between 100 and 500 volts, and the remaining 2% were logged between 100V and 500V. The highest transient recorded at this location was 872 volts. This level was the highest level recorded by Dranetz equipment on 120-volt lines.

For the combined 460 volt locations, 296 transients occurred over a 4080 hour period, yielding a composite MTBT of 9.25 hours. The highest number of transients and shortest MTBT both occurred at the Trainer Transformer Line-to-Ground Connection (See Table 2-8); 199 transients occurred with an MTBT of 7.91 hours. Of these 98.5% were recorded between the 100 volt threshold and 500 volts; the remaining ones were recorded with amplitudes between 500 and 1000 volts. The highest recorded transient amplitude for 460 volt lines at this site occurred at the Trainer Transformer Line-to-Line Connection with a peak of 1184 volts, the highest level recorded for all 460 volt lines monitored during the multiple-site overall effort.

### 3.1.9 Radar Site, St. Thomas, VI

There were eight 120 volt line locations monitored at this site. The total monitoring time for the combined locations was 28,266 hours, the

second longest length of time that any site was monitored. During this period, 4883 transients were recorded with a relatively short MTBT of 5.8 hours, as shown in Table 3-1. 97.7% of these were recorded between 50 and 100 volts, 2.0% between 100 and 500 volts, and the remainder between 500 and 1000 volts.

The location at this site where the highest number of transients occurred was at the Source connection, where 3083 transients were recorded. (See Table 2-9.) The shortest MTBT for St. Thomas was also calculated at this location and was 0.7 hours. Of the transients recorded at this location, all fell between threshold and 100 volts. The lowest number of transients at this site, 52, occurred on the Air Conditioning circuit with an MTBT of 38.0 hours.

The highest amplitude transient at this site occurred at the Radar Antenna location. The peak value, 840 volts, was the second-highest measured transient value that was recorded by Dranetz equipment on 120 volt lines at any of the sites. (See Table 2-14 for higher level transients noted on Nicolet equipment at this site).

### 3.1.10 Anti-Personnel Intrusion Test Site, Eglin AFB, FL

One 120 volt line-to-ground and two 120 volt line-to-line locations were monitored at this location, as depicted in Table 3-1. There was a total of 10,926 hours of instrument time recorded at the site. During this period, 2939 transients were registered at the 120 volt line White House location, occurring with an MTBT of 0.63 hours. This was the shortest MTBT recorded at any of the sites. Of these transients, 45.7% occurred between 50 and 100 volts and the remainder occurred between 100 and 500 volts.

On the 208 volt lines, a total of 2396 transients were recorded between 100 and 500 volts. A total of 2396 transients were recorded between 100 and 500 volts

with a composite MTBT of 3.78 hours. The main contributor to this relatively short MTBT was the Power Pole location, at which 2356 transients occurred with an MTBT of 1.92 hours. (See Table 2-10.)

The highest 120 volt line transient was recorded at 280 volts (White House location) and the highest level 208 volt line transient occurred at the Power Pole location with a peak amplitude of 218 volts.

3.1.11 FASOTRAGRUPAC, NAS Miramar, CA

As shown in Table 3-1, there were three 120 volt power line locations monitored at this site. Overall, there were 588 transients recorded over a period of 5085 hours with an MTBT of 8.6 hours. 17% of these transients occurred between threshold (50V) and 100 volts; the remaining 83% occurred between 100 and 500 volts. The highest number of transients at this site were recorded at Computer Cabinet #7. (See Table 2-11.) At this location, 348 transients occurred with an MTBT of 4.95 hours. In contrast, at the Main Power Panel location, there were only 13 transients recorded, with an MTBT of 132.5 hours.

The highest amplitude transient at this site was recorded at the Facility Wall Box location, 236 volts.

3.1.12 FASOTRAGRUPAC, NAS North Island, CA

There were a total of 5705 hours recorded at three locations on 120 volt power lines and 603 hours of instrument monitoring time recorded at a 208 volt line location at this site. (See Table 3-1.) On the 120 volt lines, a total of 603 transients were recorded at an MTBT of 9.46 hours. Of these, 62.7% occurred between threshold and 100 volts, while the remainder were registered between 100 and 500 volts. At the 208 volt line location, 46 transients were recorded at levels between 100 and 500 volts with an MTBT of 13.1 hours.

For this site, the largest number of 120 volt line transients, 234, and shortest MTBT, 12.4 hours, were both registered at the WST-3 Location. (See Table 2-12.) The lowest number of 120 volt transients for this site were recorded at the 2000 Amp Panel location, where 141 transients were recorded with an MTBT of 16.6 hours.

The highest 120 volt transient peak was recorded at the 2500 Amp Panel, 268 volts. The highest 208 volt line transient recorded was 296 volts.

3.1.13 NAVCOMSTA, Diego Garcia, Indian Ocean

A sufficient amount of data was obtained at both the "R" Site and "T" Site during the time allotted. Measurements were taken on both the 120 and 280 volt lines, as shown in Table 3-13. There were a combined total of 1765 monitoring hours on the 120V lines at five locations for a MTBT of 43 hours.

At the "R" Site, there were three 120 volt lines monitored for a combined total of 1344 monitoring hours and a MTBT of 32.78 hours. All transients occurred below 88 volts.

Three locations at the "T" Site were monitored. The AN/FRT-84 and the MINI-AS-COMM Power Panel 120 volt lines produced no detectable transients during a combined 421 monitoring hours. The 280 volt line of the AN/FRT-85 was monitored for 122 hours for a MTBT of 8.75 hours, with 39% of the transients occurring above 100 volts with the highest noted at 404 volts.

## 3.2 TRANSIENT AMPLITUDE DISTRIBUTIONS

Figures 3-1 through 3-18 provide graphical depictions of the cumulative complementary distribution functions for the ac power lines that were monitored on an overall site-by-site basis. These graphs correspond on a one-to-one basis with the site entries in Table 3-1 with the exception of the NAS Patuxent River

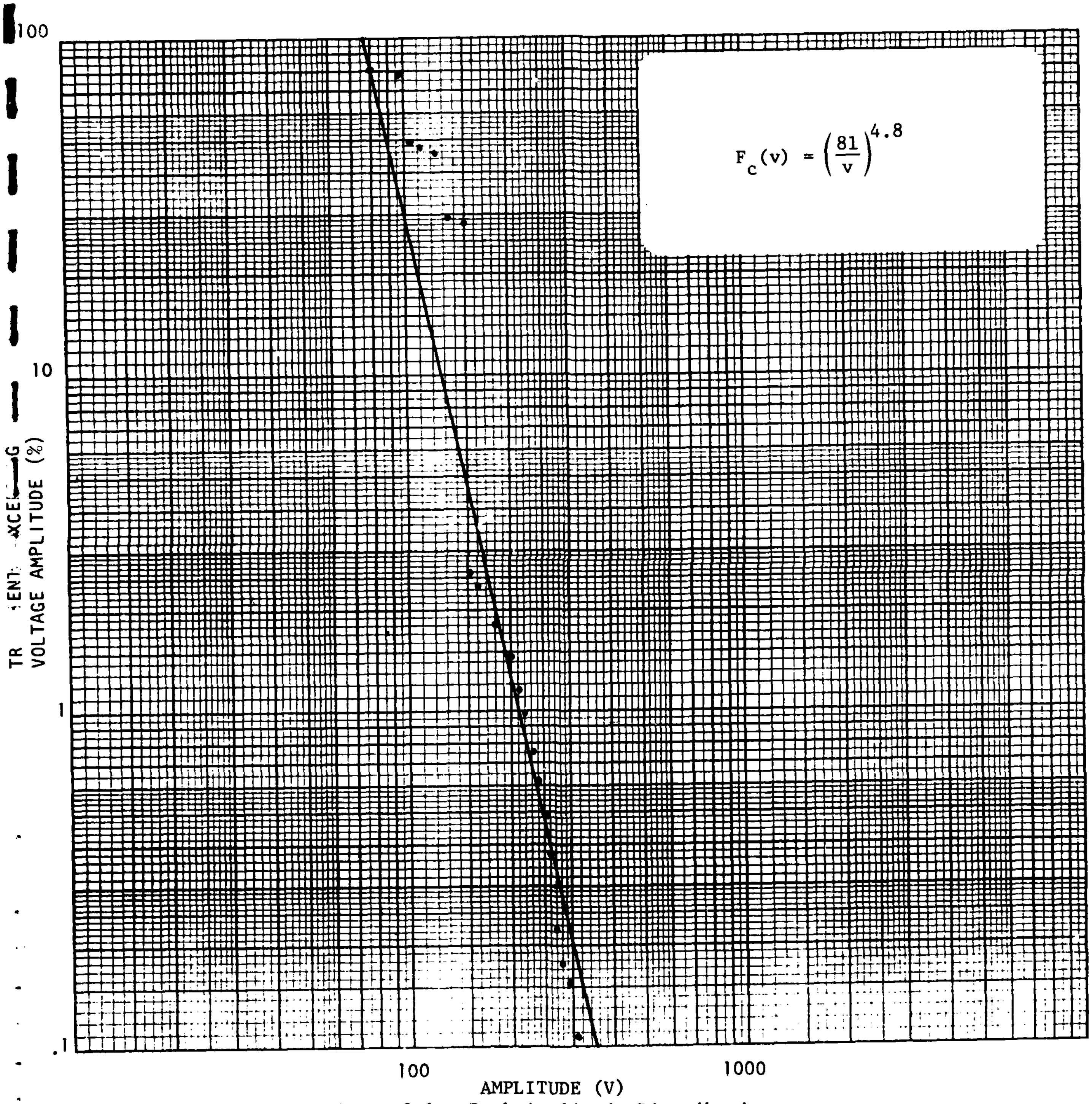



Figure 3-1. Peak Amplitude Distribution
All 120V
NAS Key West, FL

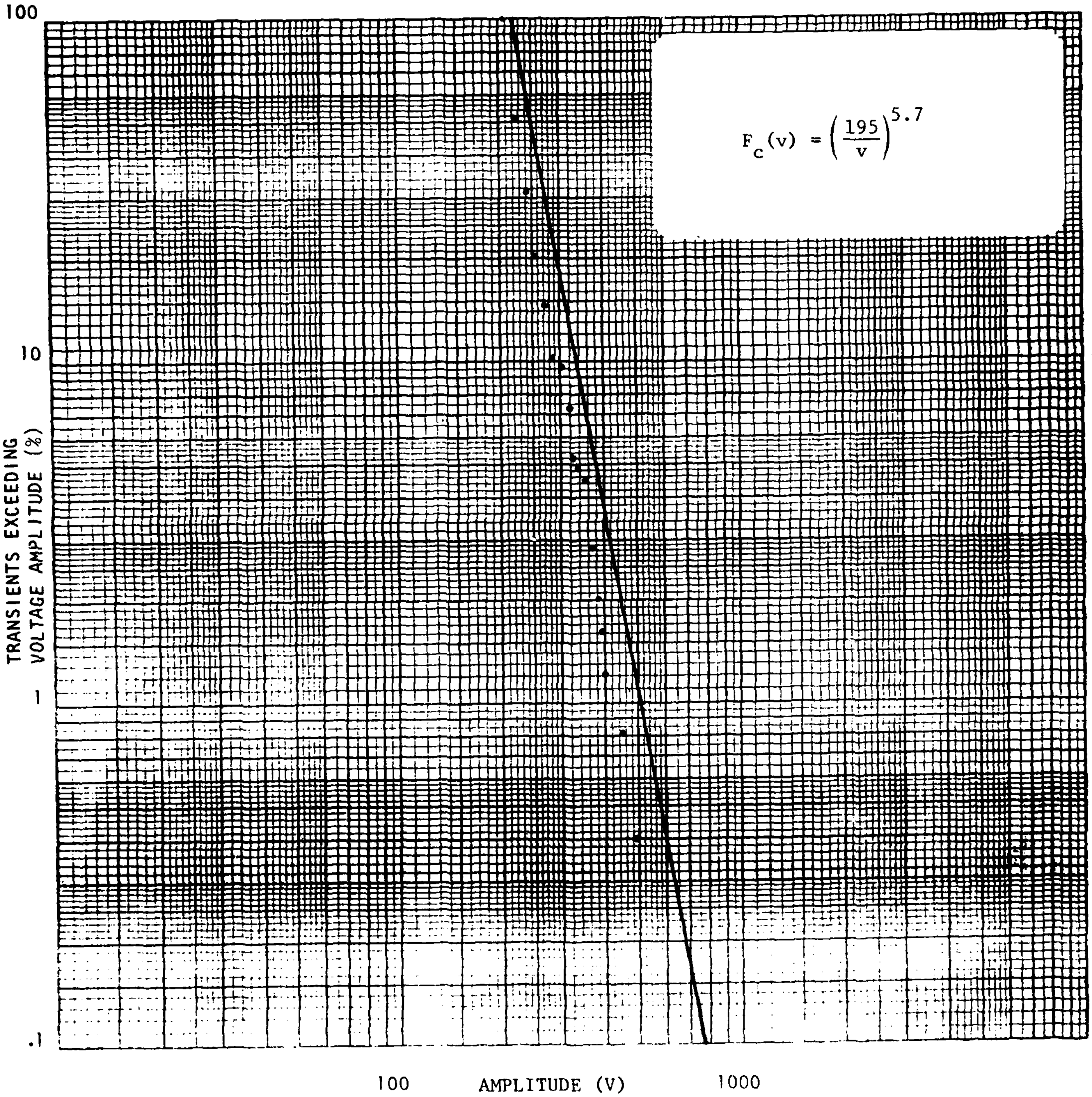



Figure 3-2. Peak Amplitude Distribution
All 460V
NAS Key West, FL

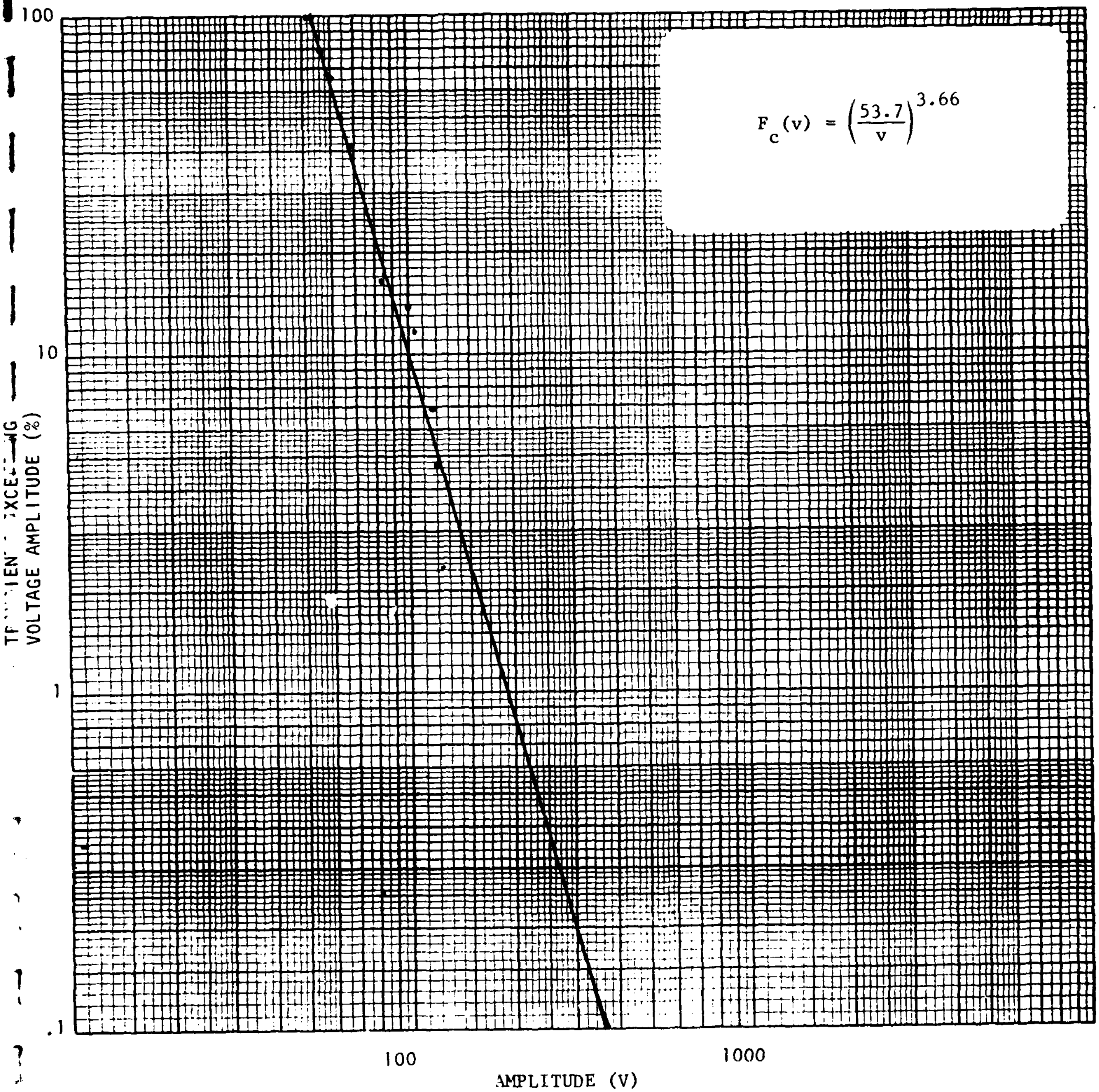



Figure 3-3. Peak Amplitude Distribution
All 120V
U.S. Naval Observatory, Washington, DC

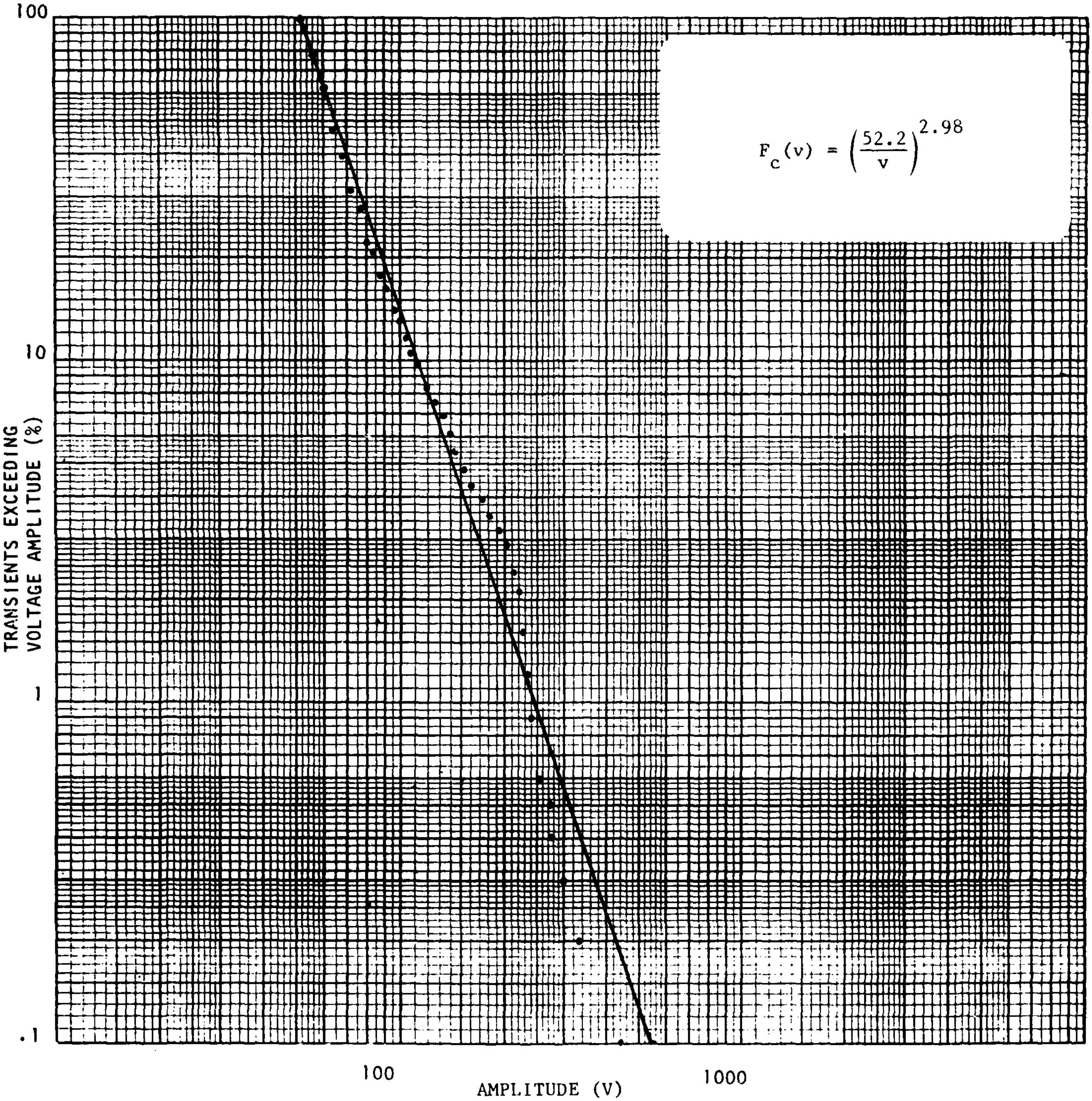



Figure 3-4. Peak Amplitude Distribution
All 120V
ASW Training Center, Norfolk, VA

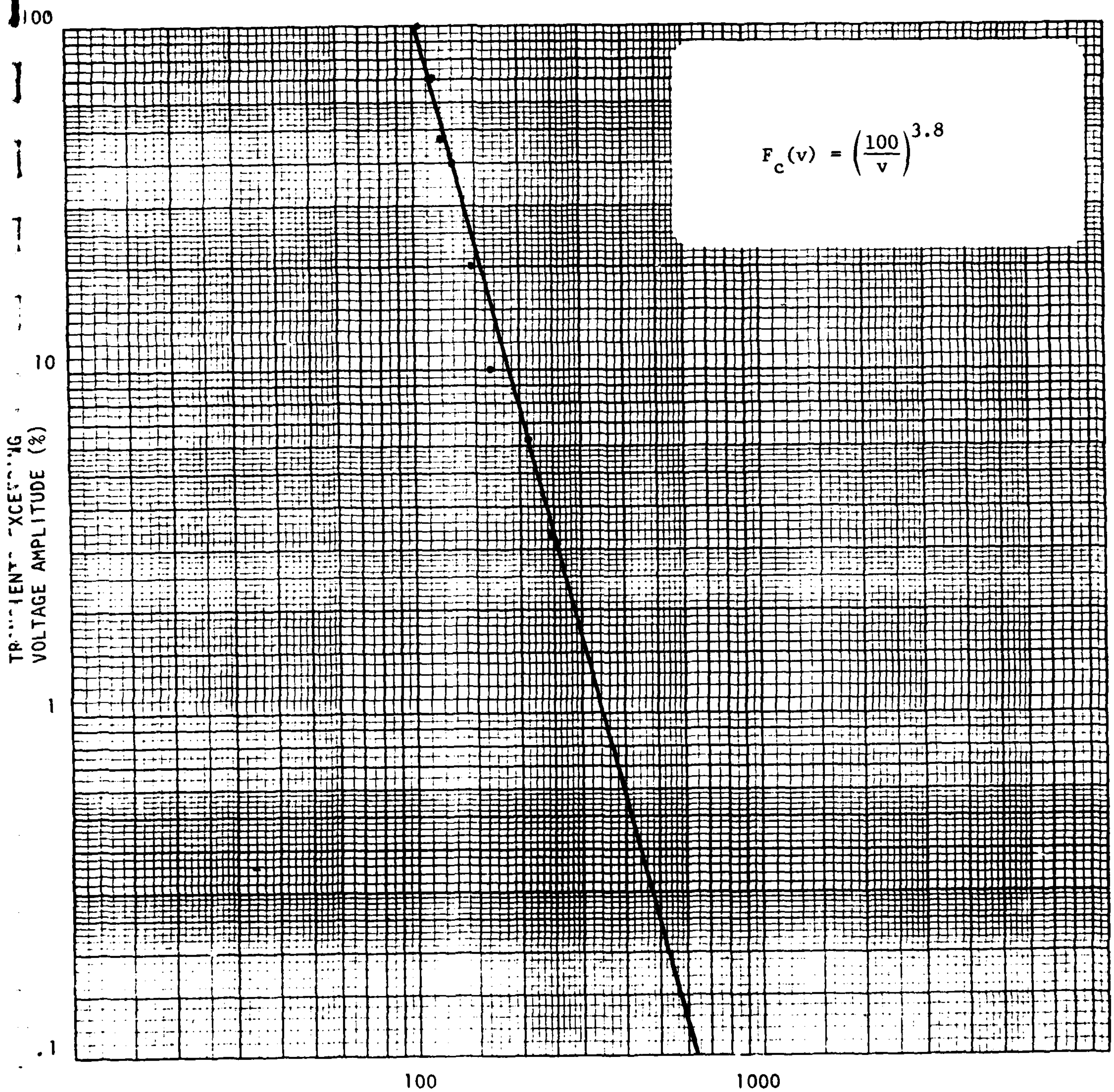



Figure 3-5. Peak Amplitude Distribution
All 280V
ASW Training Center, Norfolk, VA

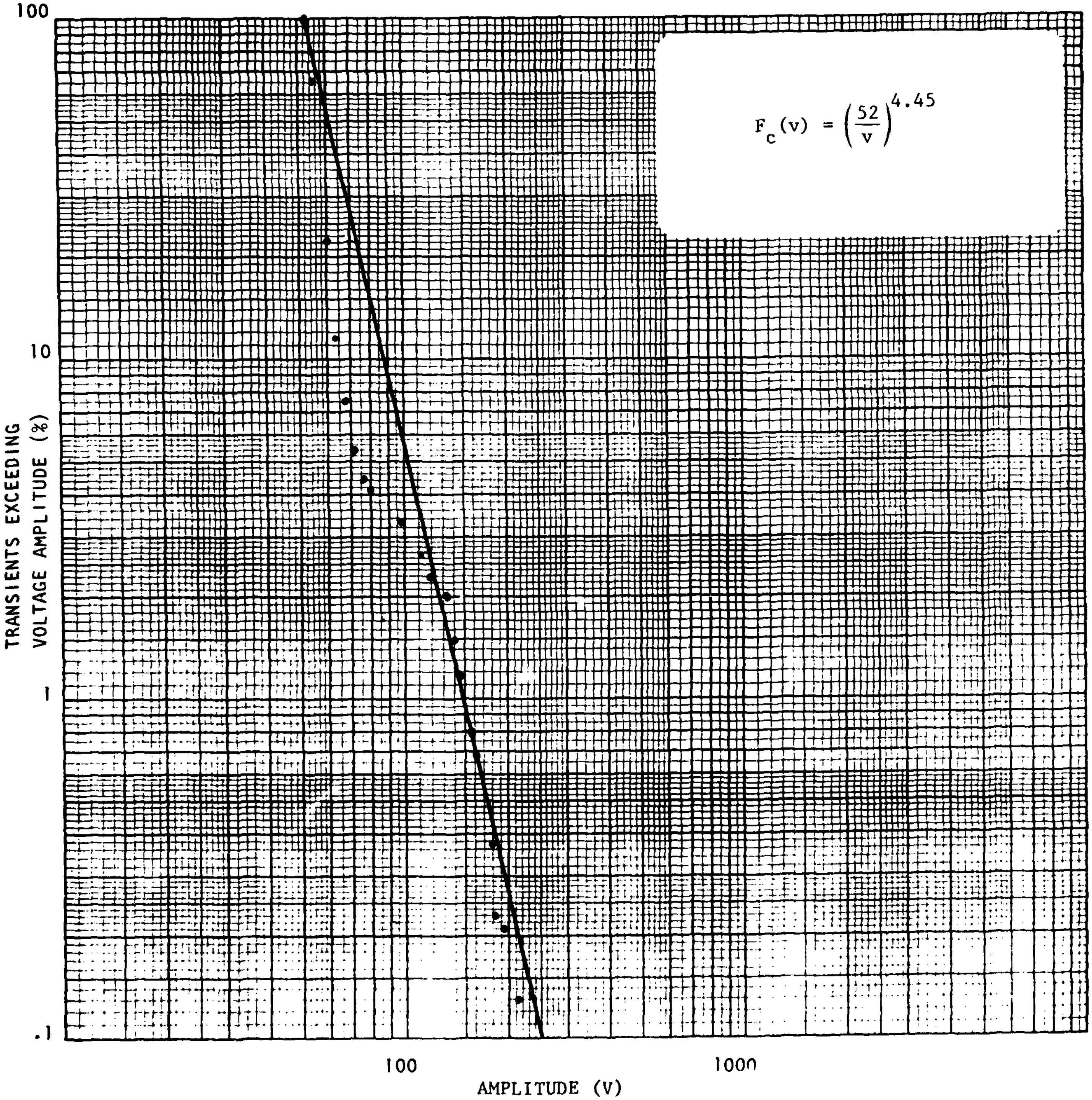



Figure 3-6. Peak Amplitude Distribution
All 120V
Radar Site, San Juan, PR

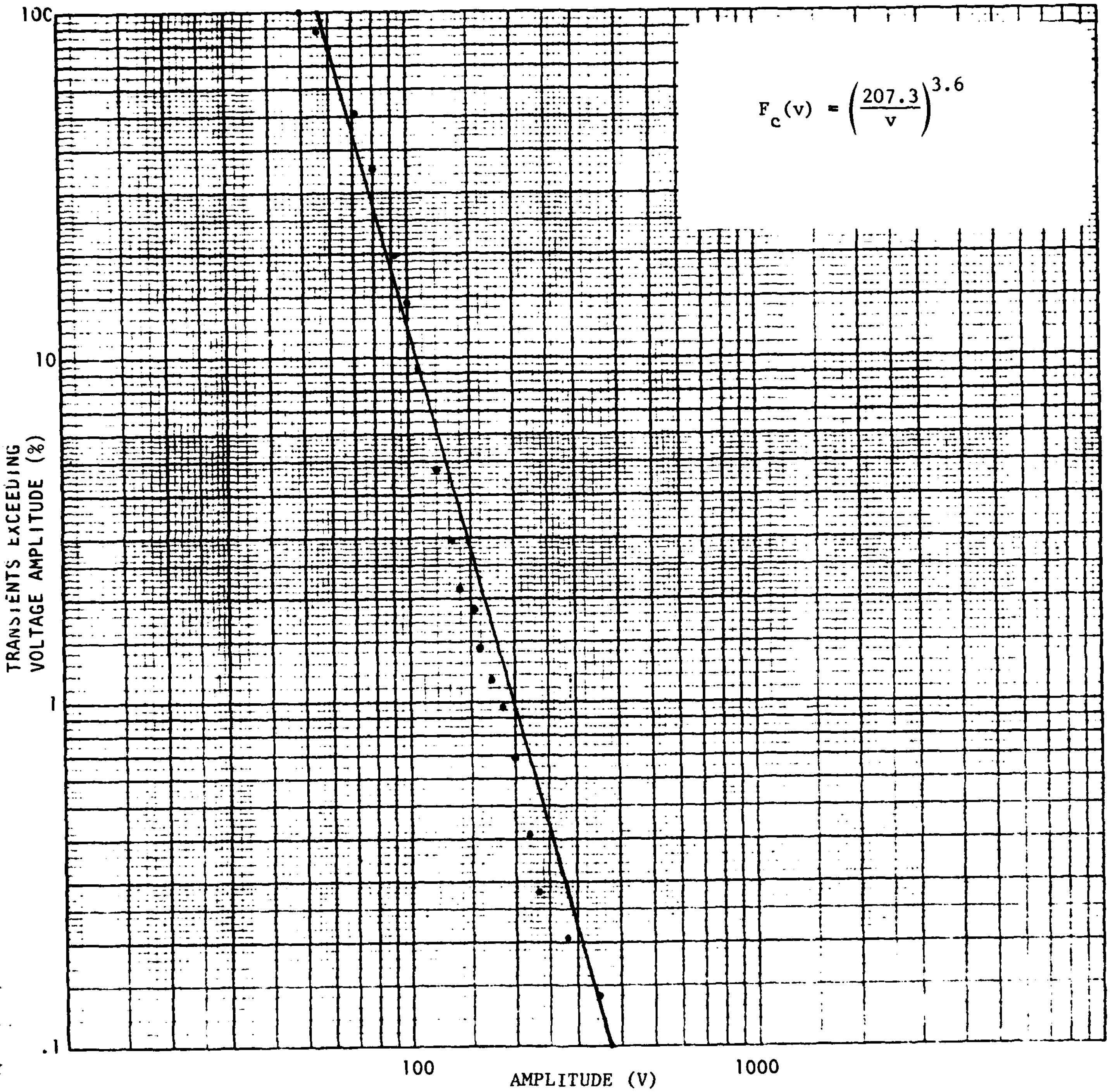



Figure 3-7. Peak Amplitude Distribution
All 120V
Fleet Training Center, Bldg. 127
Dam Neck, VA

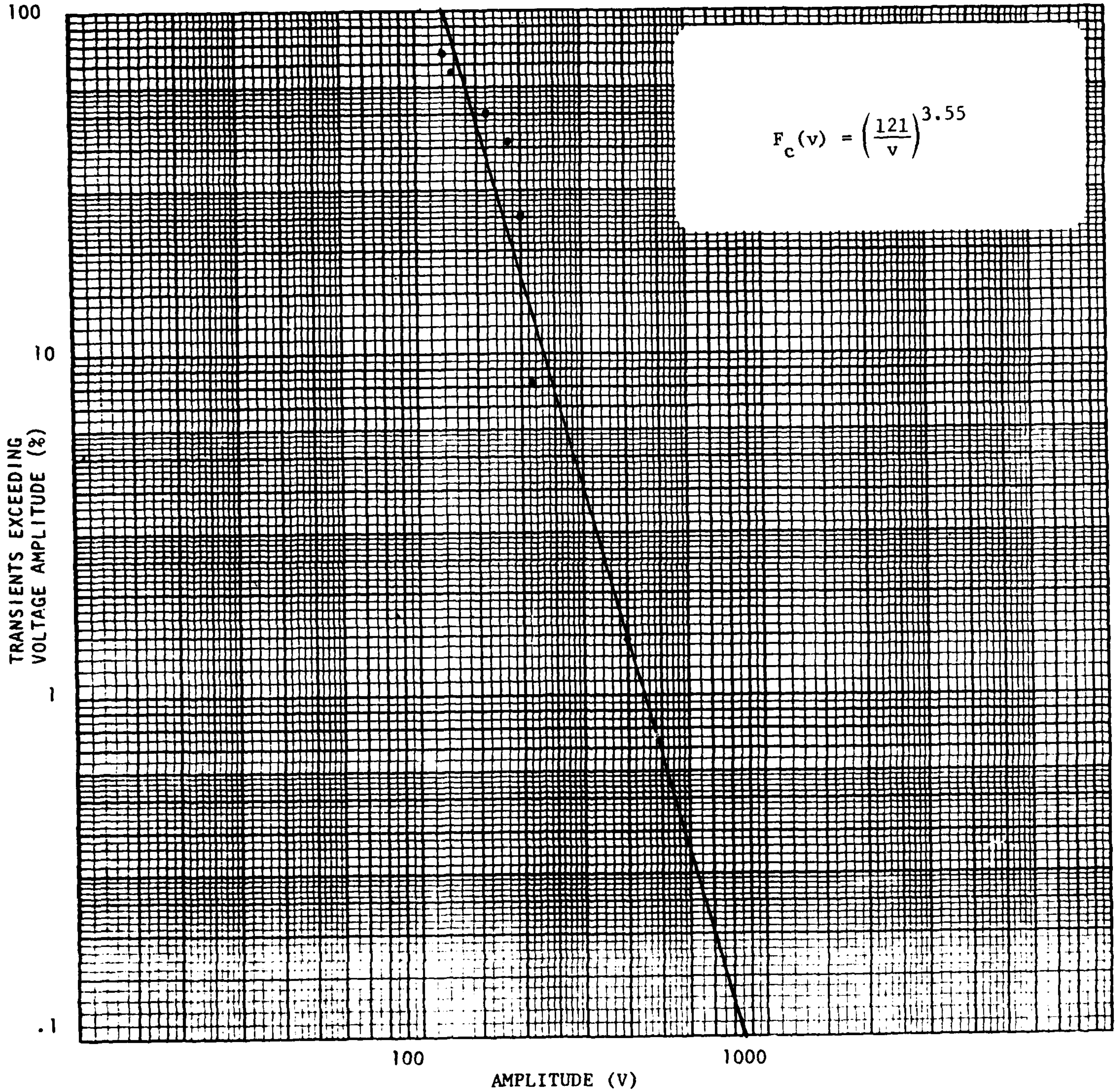



Figure 3-8. Peak Amplitude Distribution
All 120V
Navy Amphibious Base, Little Creek, VA

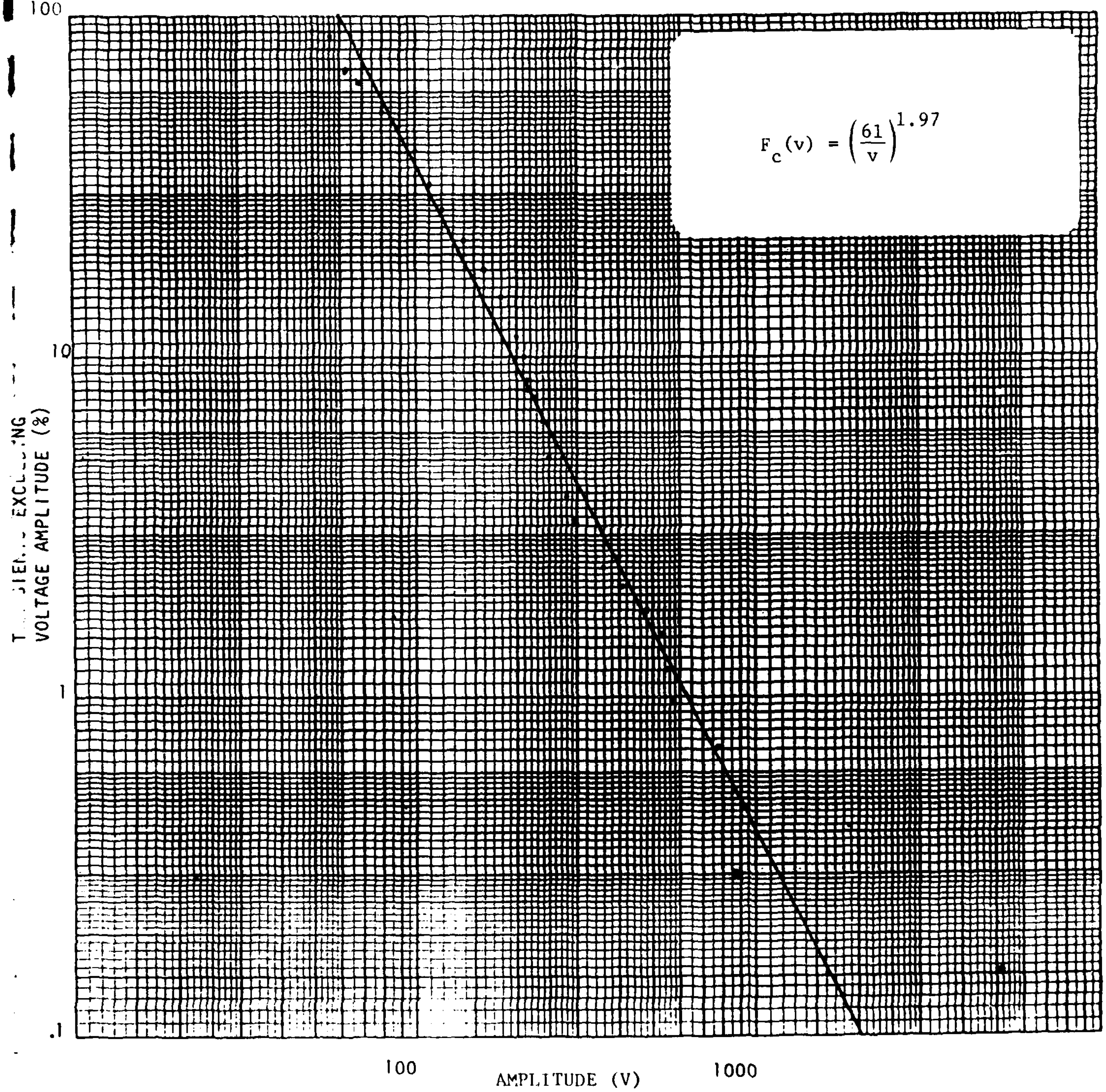



Figure 3-9. Peak Amplitude Distribution
All 120V
NAS Oceana, VA

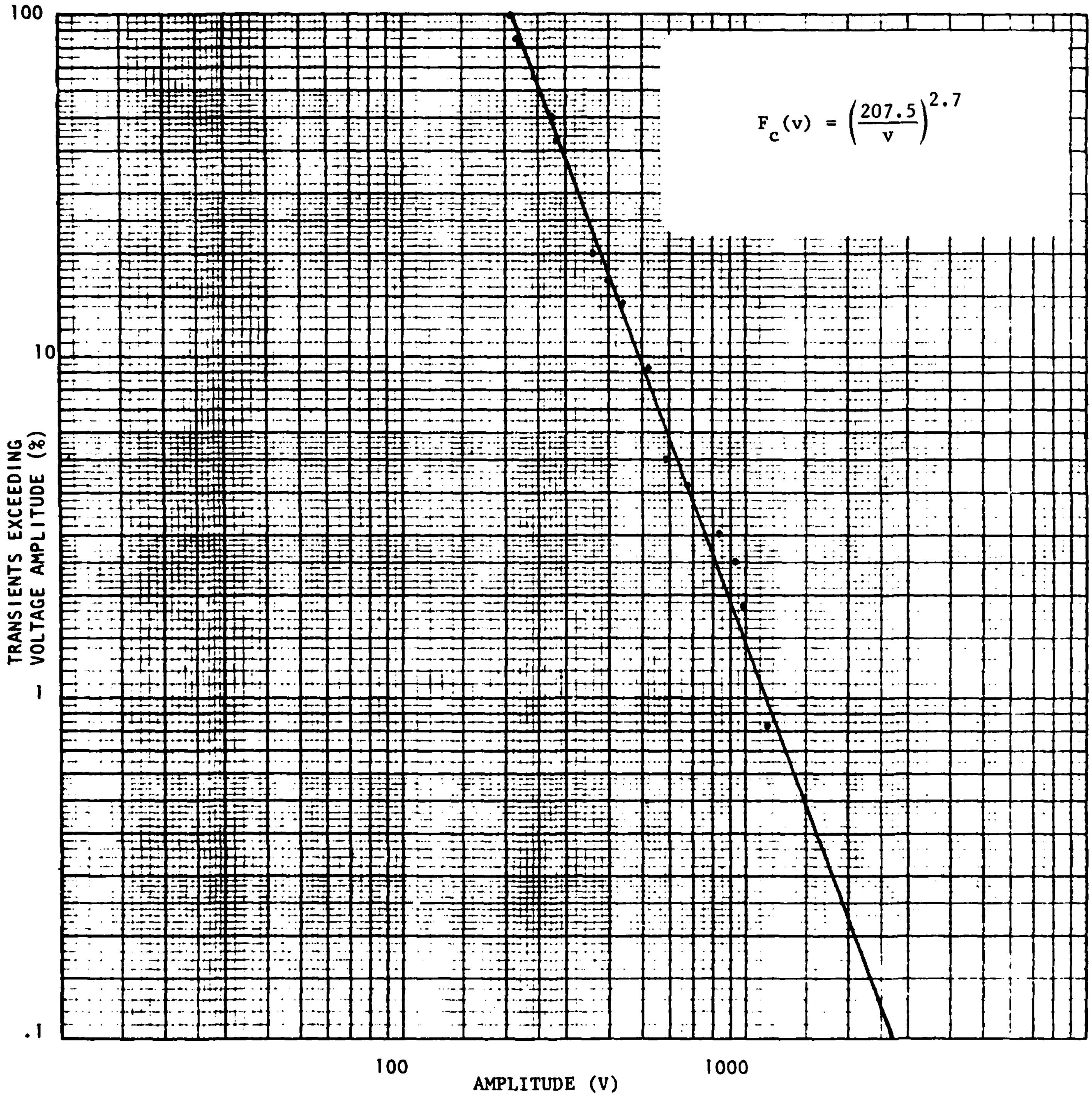



Figure 3-10. Peak Amplitude Distribution
All 460V
NAS Oceana, VA

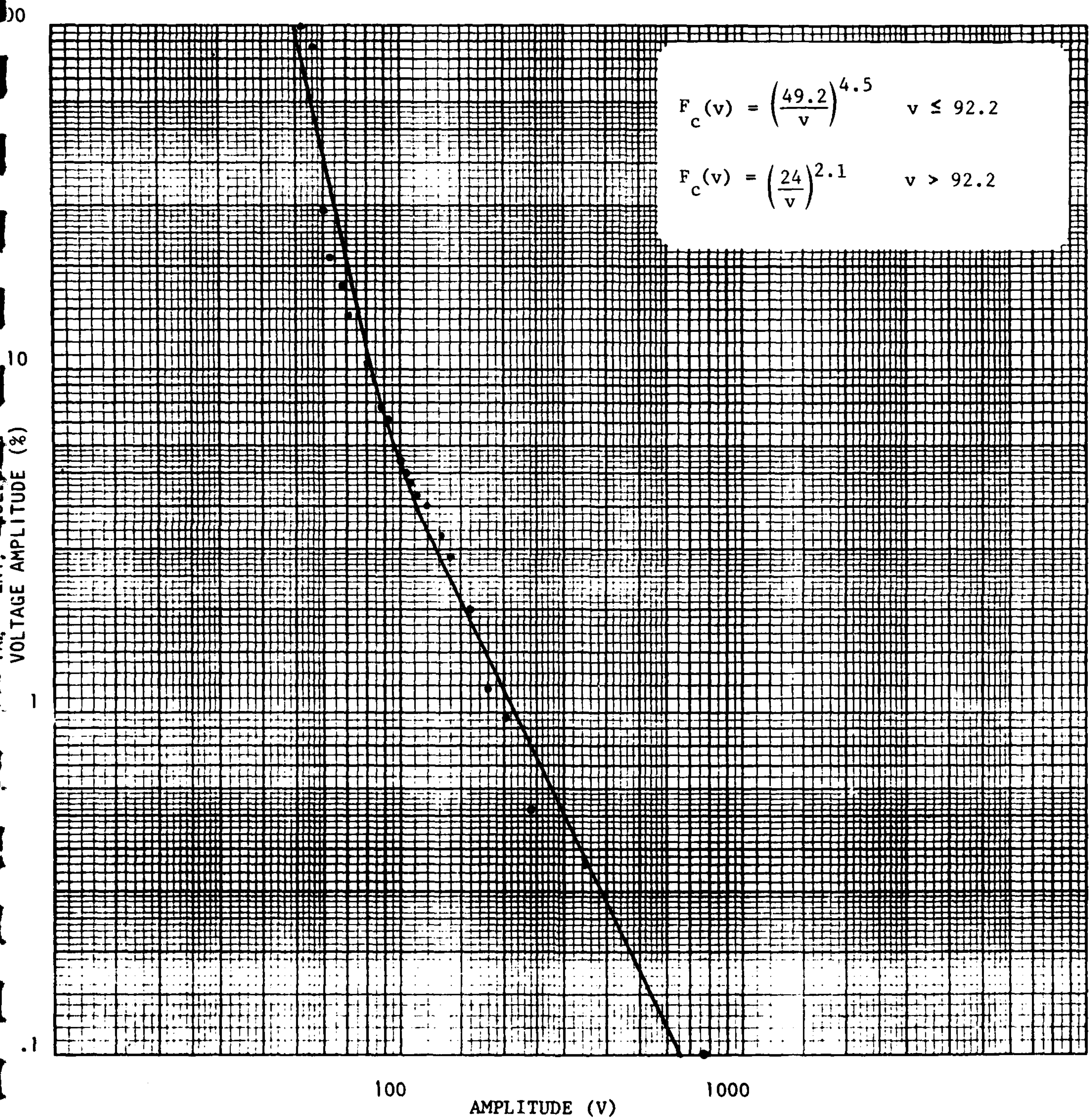



Figure 3-11. Peak Amplitude Distribution
All 120V
Radar Site, St. Thomas, VI

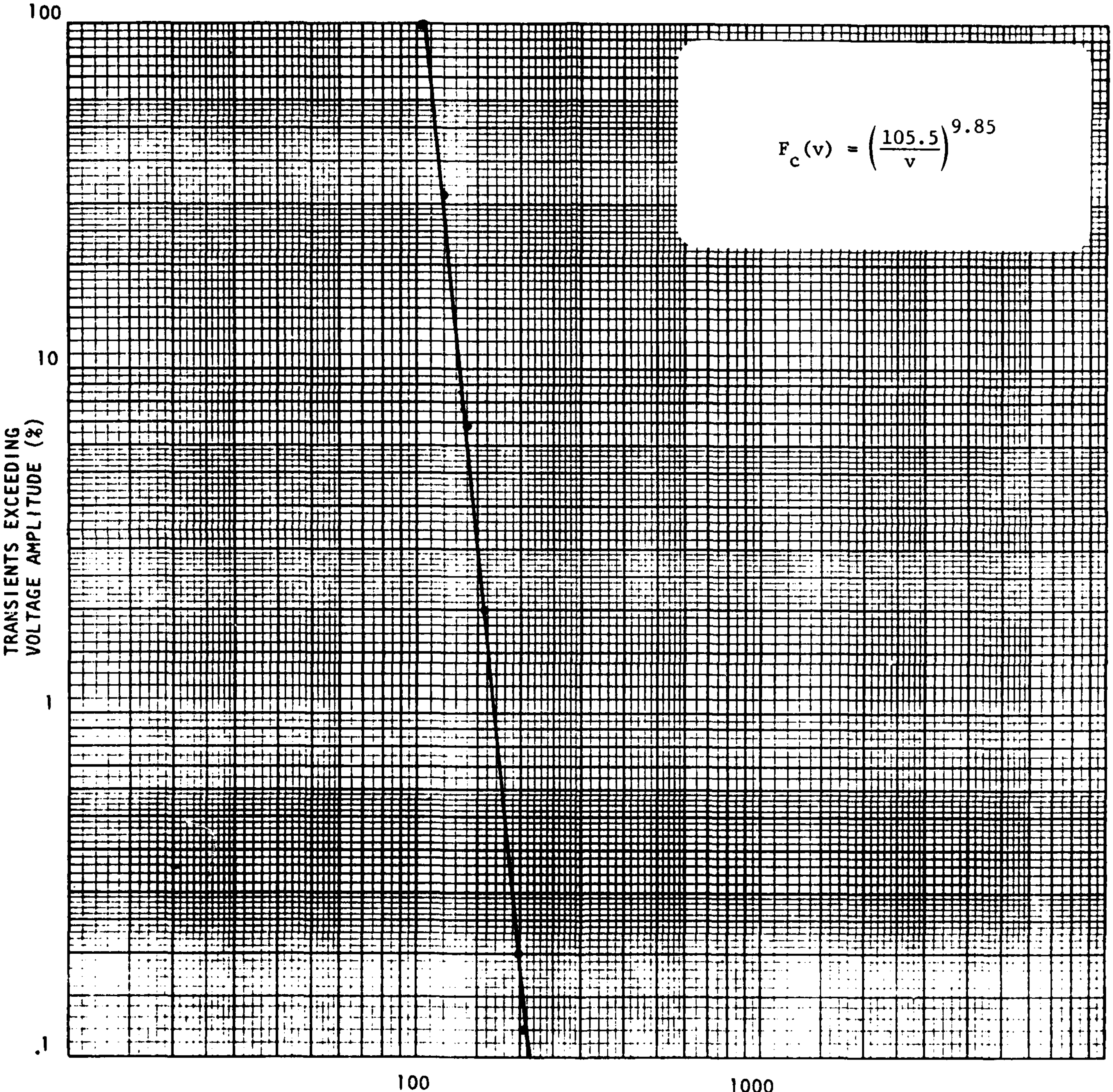



Figure 3-12. Peak Amplitude Distribution
All 208V
Anti-Personnel Intrusion Test Site, Eglin AFB, FL

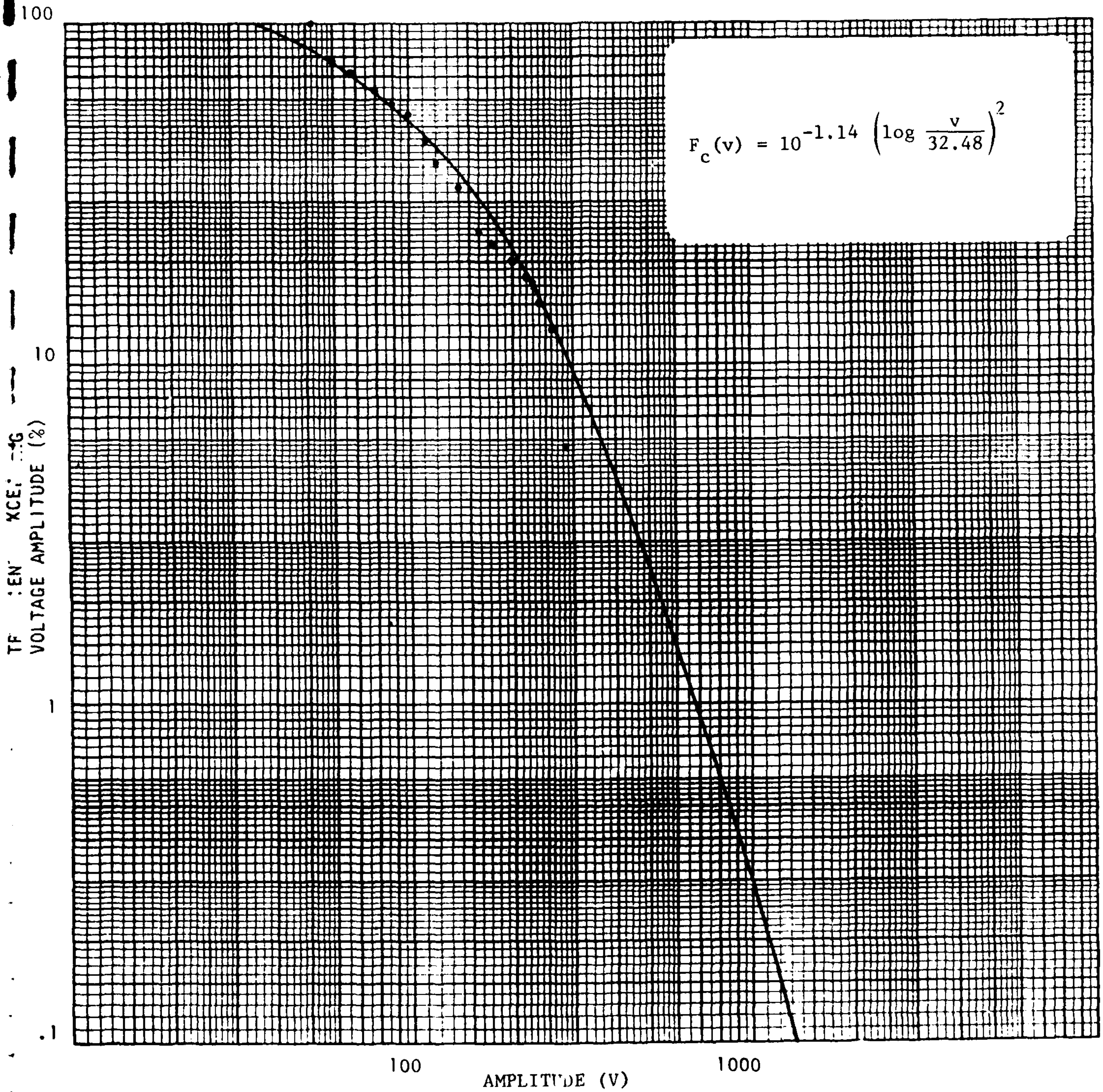
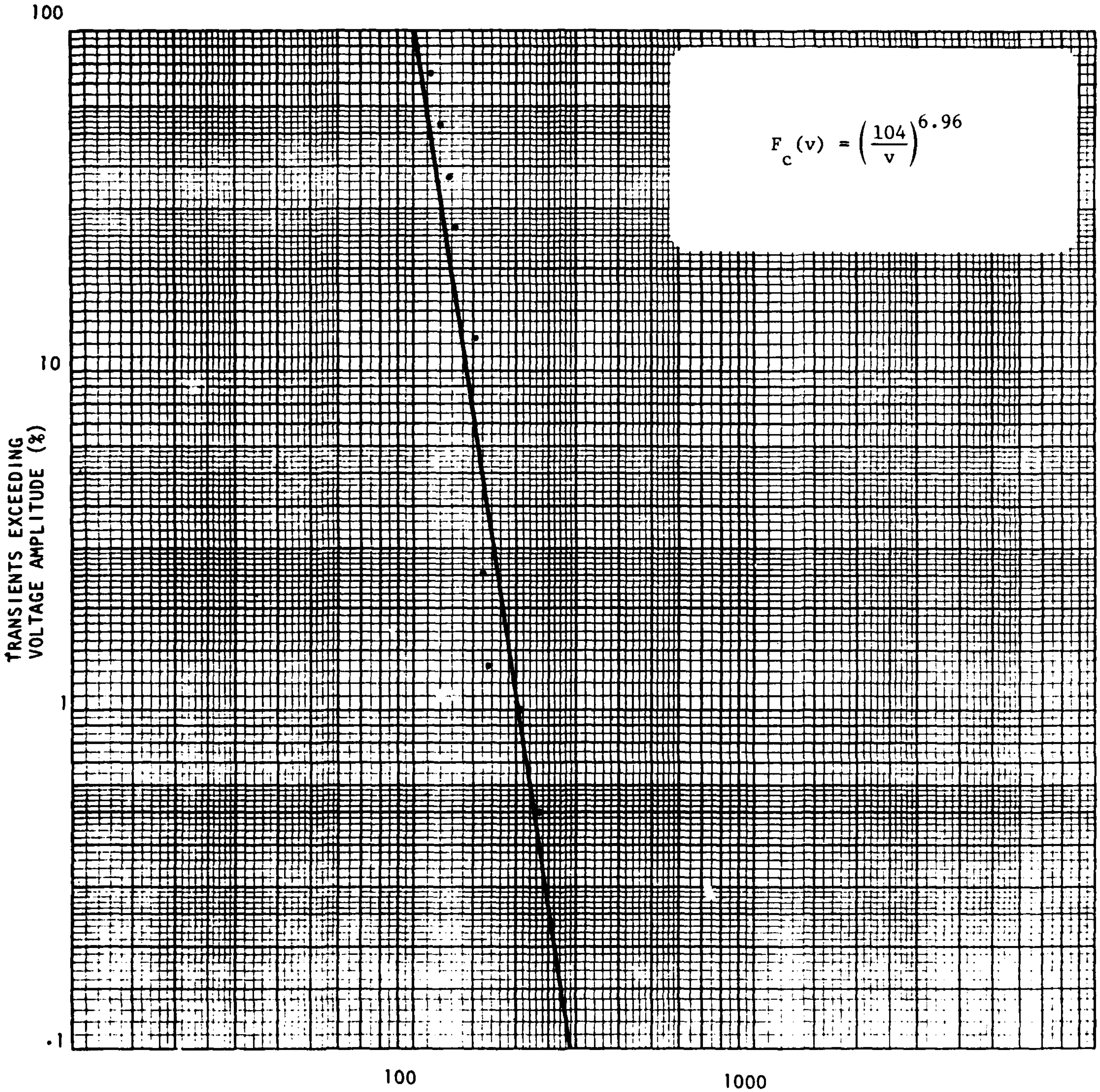



Figure 3-13. Peak Amplitude Distribution
All 120V
Anti-Personnel Intrusion Test Site, Eglin AFB, FL




AMPLITUDE (V)

Figure 3-14. Peak Amplitude Distribution
All 120V
FASOTRAGRUPAC, NAS Miramar, CA

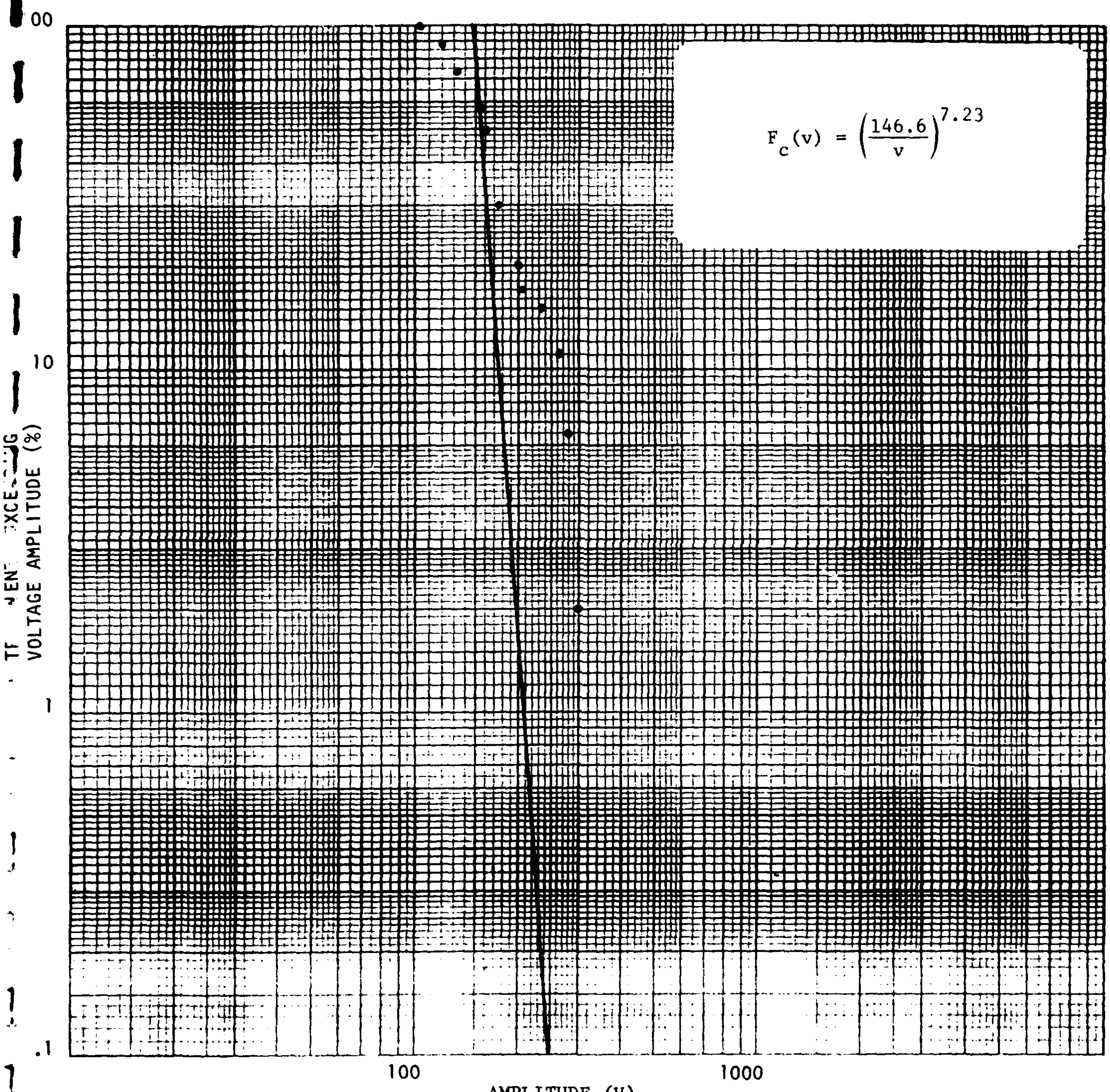



Figure 3-15. Peak Amplitude Distribution
All 208V
FASOTRAGRUPAC, NAS North Island, CA

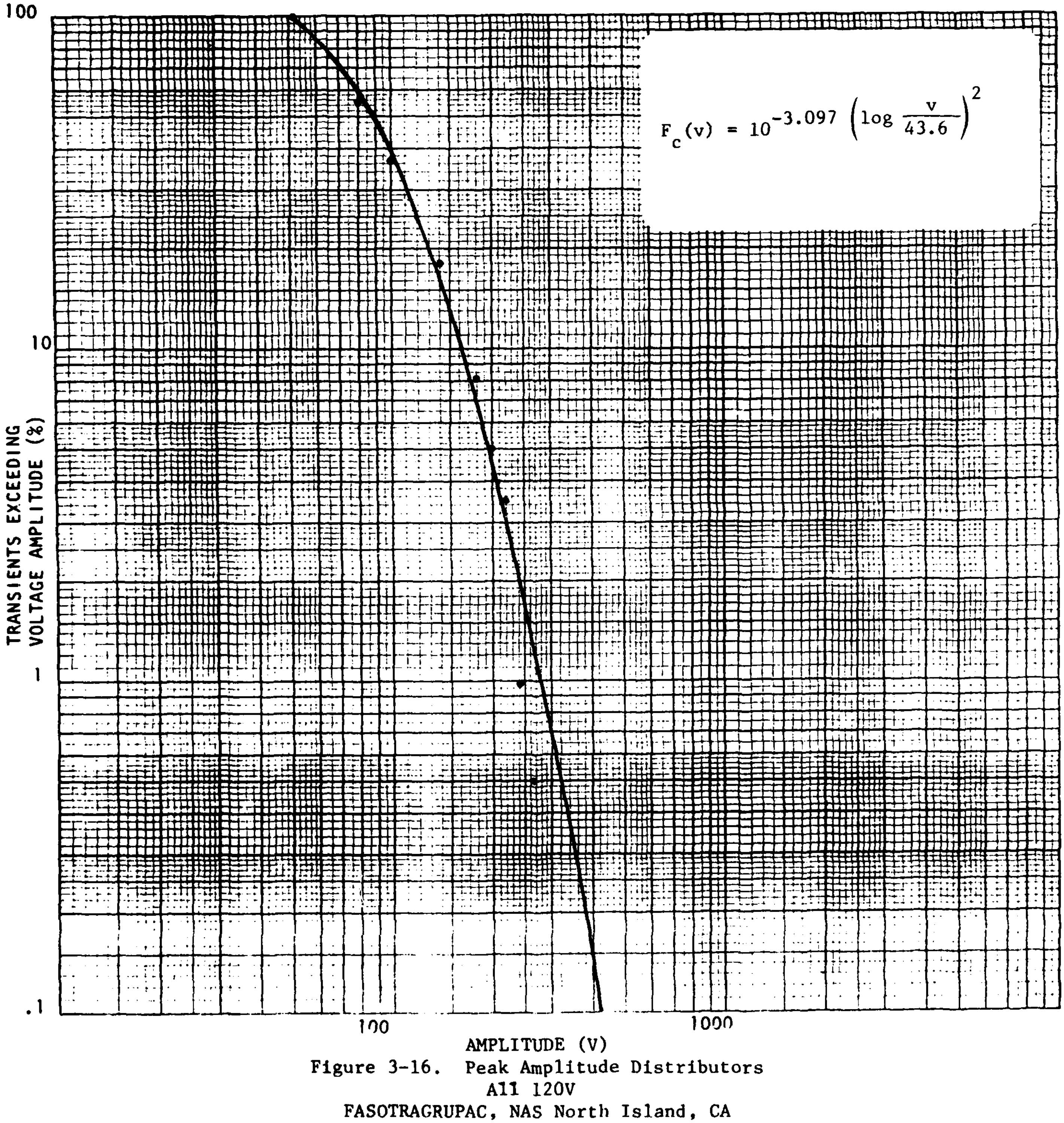



Figure 3-16. Peak Amplitude Distributors
All 120V
FASOTRAGRUPAC, NAS North Island, CA

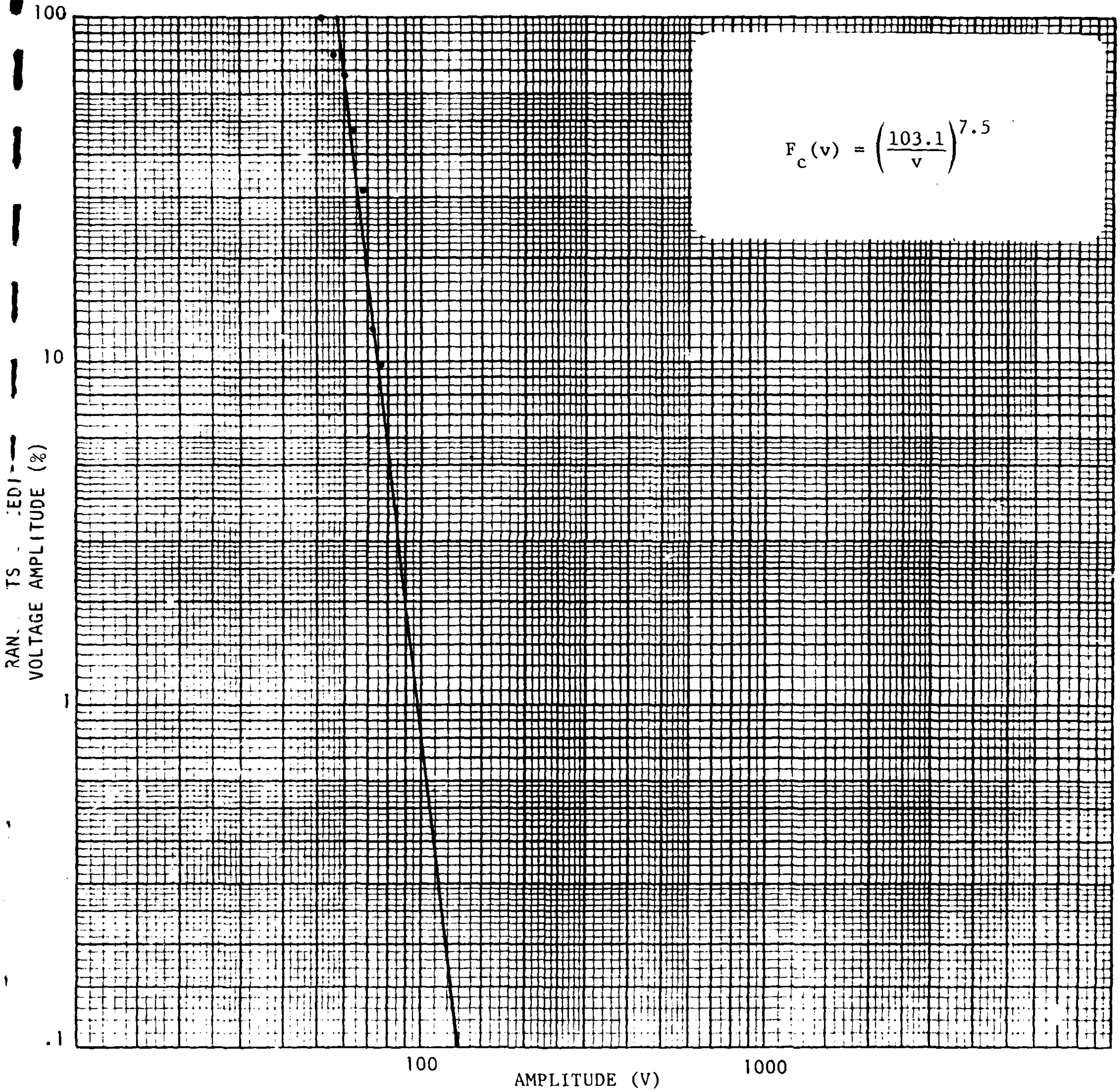



Figure 3-17. Peak Amplitude Distribution
All 120V
NAVCOMSTA, Diego Garcia, Indian Ocean

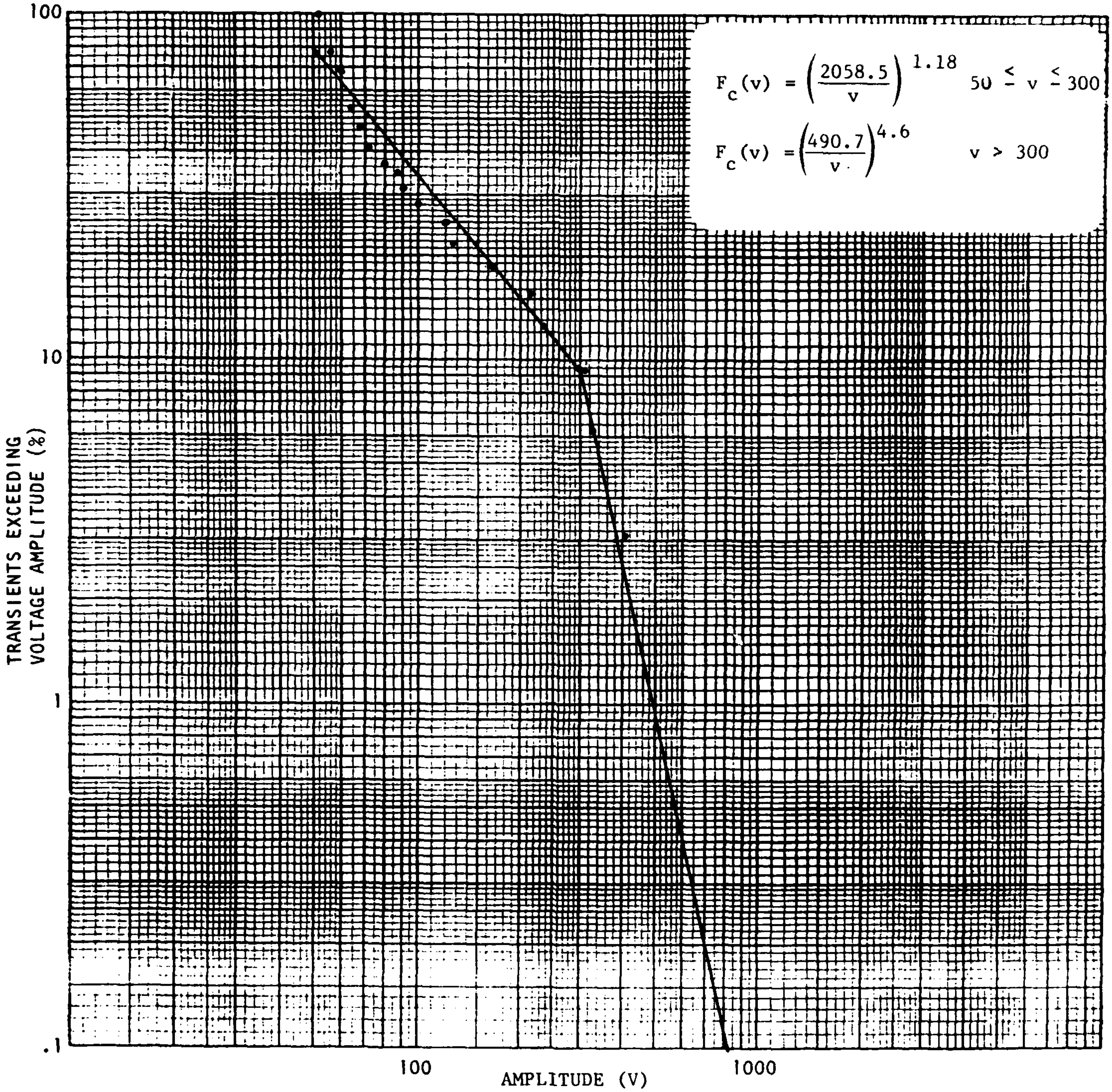



Figure 3-18. Peak Amplitude Distribution
All 280V
NAVCOMSTA, Diego Garcia, Indian Ocean

entry. At this location, only one transient was recorded, so no graphical display was constructed. Equations describing the curves shown in each figure are provided in the upper right-hand portion of each graph.

### 3.3 COMPOSITE STATISTICAL RESULTS AND TRANSIENT DISTRIBUTIONS

For this portion of the analysis the transient statistics for all the Phase II sites were compiled and combined. These composite statistics are listed in Table 3-2 and are differentiated by voltage type. Of the total time that ac power lines were monitored, 84.7% of the hours were spent on 120V ac power lines in the line-to-ground mode. The 24,166 transients recorded over a monitoring period of 107,828 hours yielded an MTBT of 4.46 hours. 60.2% of these transients occurred with amplitudes between 50 and 100 volts, 39.7% occurred between 100 volts and 500 volts and the remaining 0.1% were recorded between 500 and 1000 volts. The maximum level recorded on 120V lines in the line-to-ground mode was 872 volts, registered at the NAS Oceana site.

7.8% of the total monitoring time was expended on 208-volt (120V line-to-line) lines. The composite MTBT was 3.96 hours, the shortest MTBT for the four different line voltages that were monitored. All of the transients registered on these lines occurred between threshold (100V) and 500 volts. The maximum recorded transient occurred at NAS North Island, with an amplitude of 296 volts.

On 280-volt lines, 62 transients were recorded over an instrument monitoring period of only 2282 hours. The resultant MTBT was 36.8 hours, the longest among the four voltage types voltage shown in the table. As on the 208-volt lines, all transients that were recorded occurred with peak amplitudes between 100V (threshold) and 500 volts. The maximum 280 volt line transient level, 404 volts, was recorded at NAVCOMSTA, Diego Garcia.

TABLE 3-2

COMPOSITE AC POWER LINE STATISTICS

| Total Hours | Test Site | Power Line Parameters | | TRANSIENT TEST RESULTS | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Voltage | Freq. | Numbers of Transients Measured | Mean Time Between Transients (Hrs.) | AMPL Between 50V & 100V | AMPL Between 100V & 500V | AMPL Between 500V & 1000V | AMPL > 1000V | Maximum AMPL Level Recorded |
| 107828 | ALL | 120V | 60 Hz | 24166 | 4.46 | 14539 | 9613 | 14 | 0 | 872 |
| 9669 | ALL | 208V | 60 Hz | 2442 | 3.96 | N/A | 2442 | 0 | 0 | 296 |
| 2282 | ALL | 280V | 60 Hz | 62 | 36.81 | 23 | 39 | 0 | 0 | 404 |
| 7446 | ALL | 460V | 60 Hz | 542 | 13.11 | N/A | 531 | 10 | 1 | 1184 |

There were 542 transients recorded on 460-volt lines over a period of 7446 hours with an MTBT of 13.74 hours. 98% of these occurred with amplitudes between 100 volts and 500 volts. One 460-volt line transient occurred with an amplitude greater than 1000 volts. The amplitude of this transient was 1184 volts and it was recorded NAS Oceana.

Figures 3-19 through 3-22 depict the complementary cumulative distribution for the four line voltage types, 120V, 208V, 280V and 460, respectively. Equations representing the approximate distribution are provided in the upper right hand corner of these graphs. Although the 872-volt transient maximum is not plotted on Figure 3-19, it was used in calculating the 120-volt transient distribution. The cumulative complementary distribution function for v = 872 volts was calculated to be 0.0043%. Using the approximation curve shown in Figure 3-19 and described by the corresponding equation, a probability distribution of only 0.0163% is predicted for this voltage level.

## 3.4 TRANSFORMER COUPLING EFFECTS

Transformer transient coupling was examined at several points at NAS Key West, ASWTC Norfolk and NAS North Island. For all transformer-coupled points at these locations, no correlation was observed between transient excursions on one side of a transformer and those occurring on the other side. In other words, any transient occurring on one side of a transformer was not reflected by a corresponding transient on the other side of the transformer that exceeded the 50 volt instrumentation threshold.

At the Key West Site, the transformer-coupled points that were examined are identifiable in Figure 2-1. Specifically, coupling effects between transients occurring between Locations 1 and 2, and between Locations 1 and 5 were

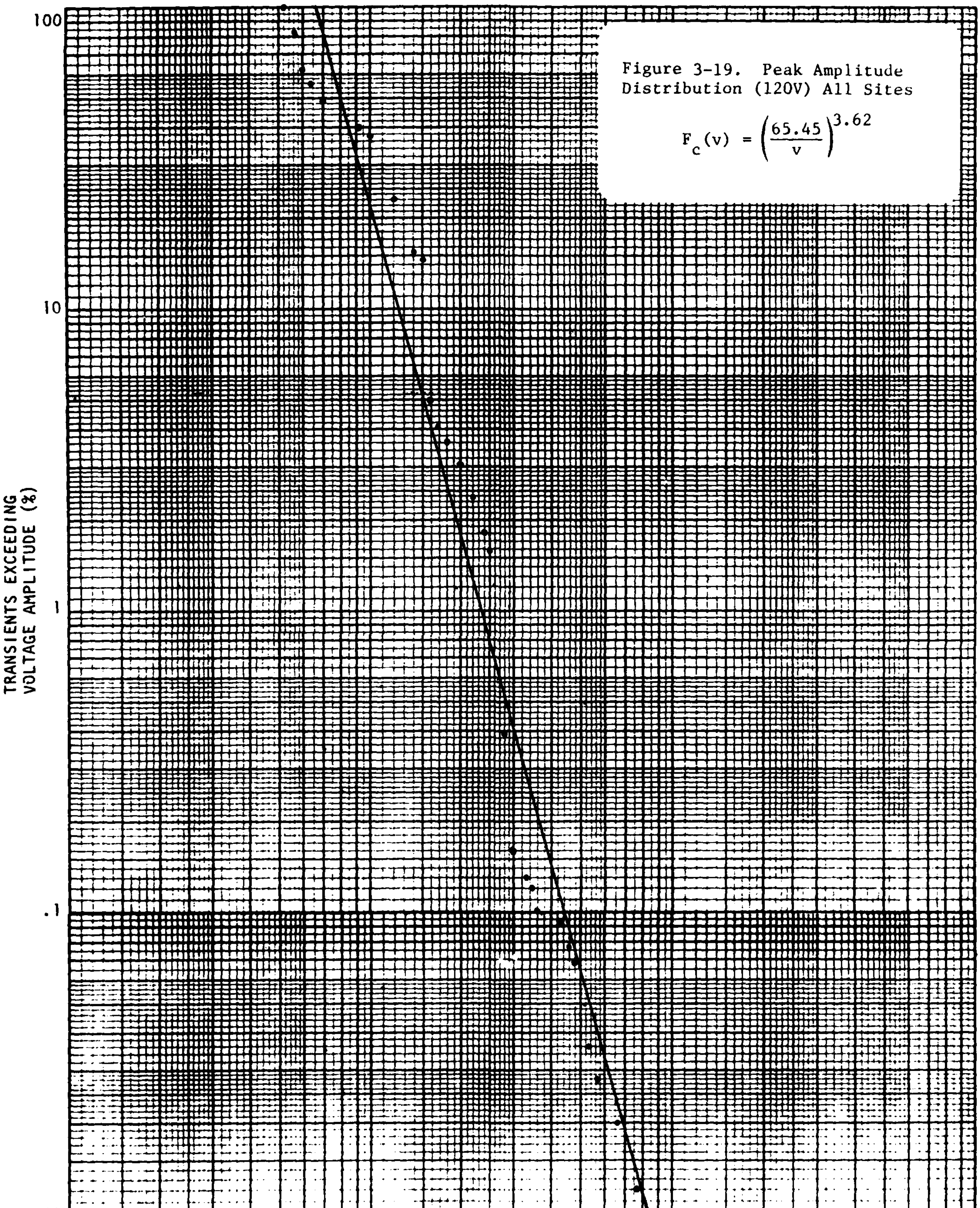



Figure 3-19. Peak Amplitude Distribution (120V) All Sites

$$F_c(v) = \left(\frac{65.45}{v}\right)^{3.62}$$

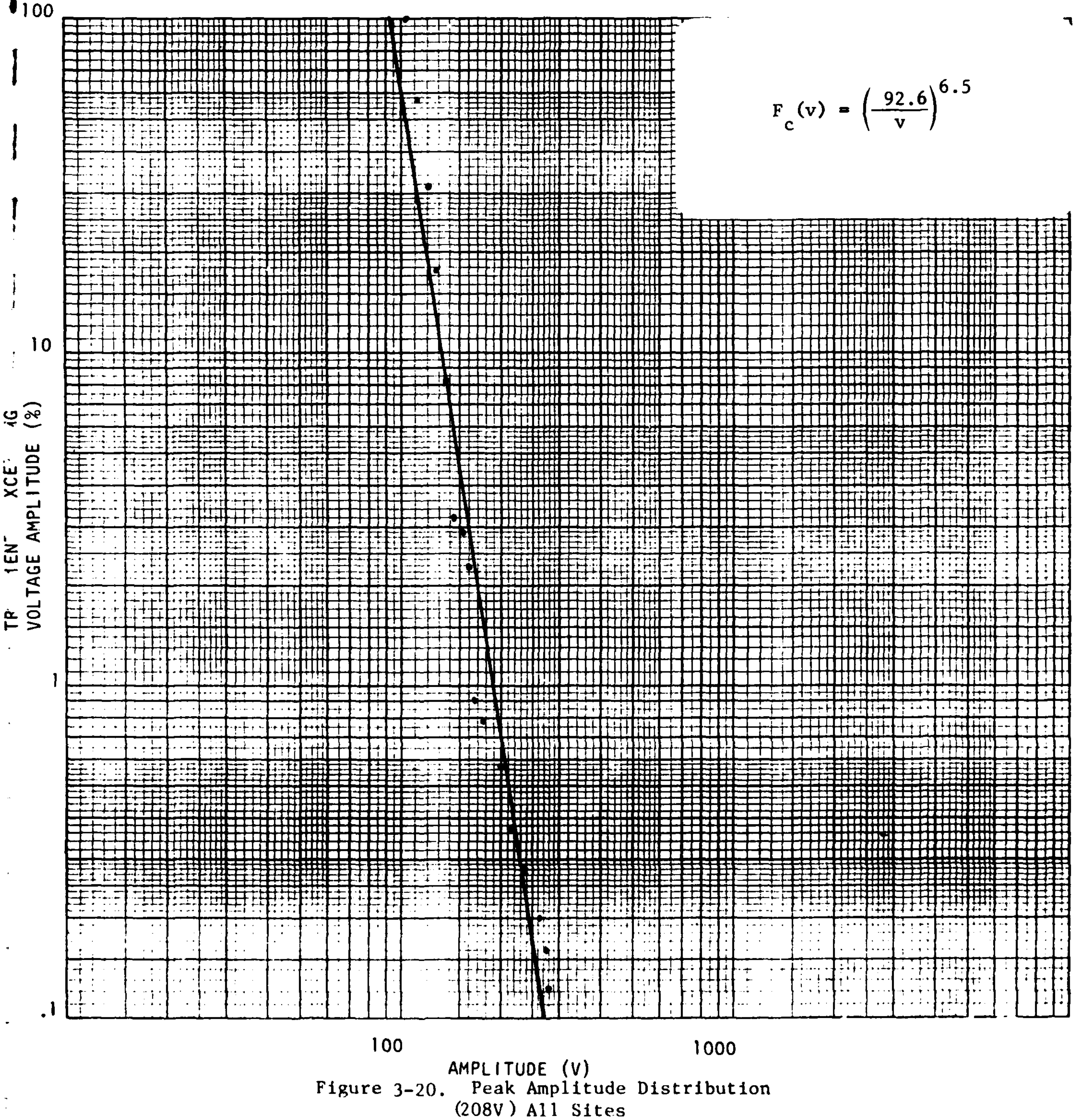



Figure 3-20. Peak Amplitude Distribution (208V) All Sites

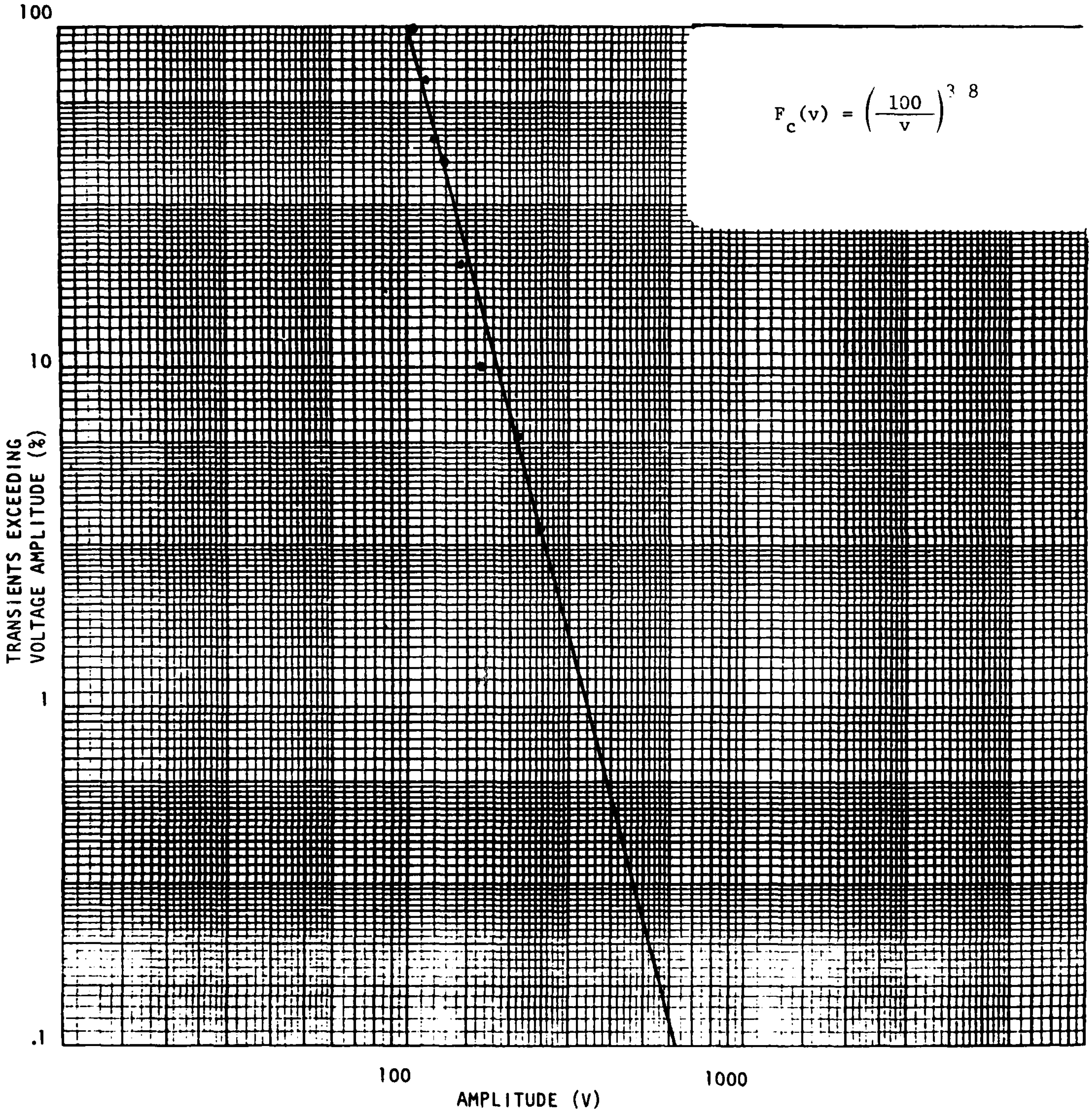



Figure 3-21. Peak Amplitude Distribution
(280V) All Sites

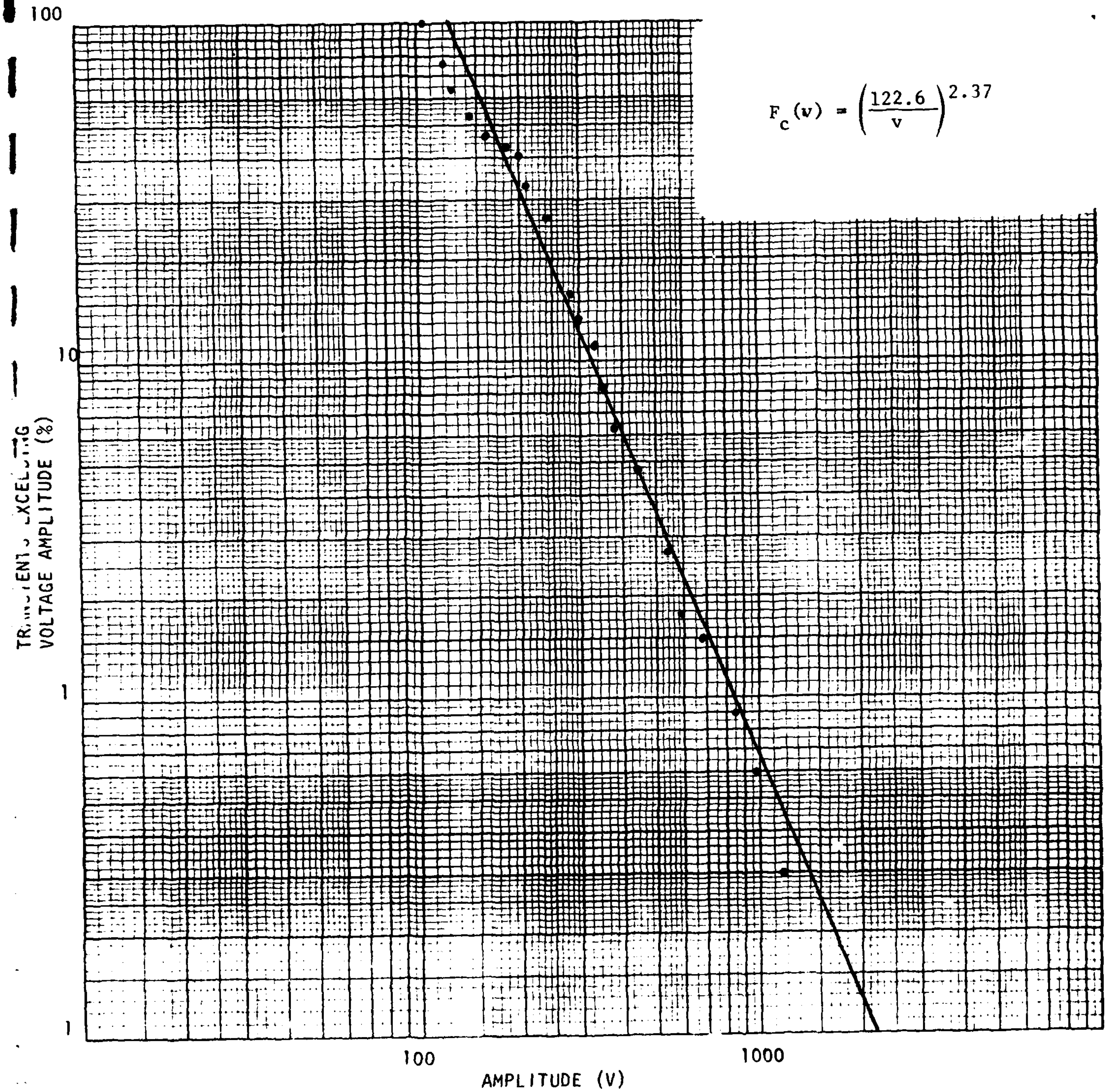



Figure 3-22. Peak Amplitude Distribution
(460V) All Sites

investigated. The locations examined at Norfolk were all at Building CEP-162 and are depicted back in Figure 2-2. Transient coupling between Locations 2 and 3 and between Locations 2 and 4 were examined at this site.

From examination of the above, it appeared that transformers have the effect of buffering (and isolating) transients occurring on one side of the transformer from those occurring on the other. The quantitative isolation levels for the cases encountered are not known. Separate tests performed by NESEA of transients coupled through power line isolation transformers[a] indicate that the transient transfer characteristic is highly dependent on the transformer load impedance.

## 3.5 THRESHOLD CHANGES

In the collection of transient events, an important parameter is the threshold to which the instrumentation used to record transients was set. As indicated earlier, this threshold was 50, 100 or 200 volts and no transient was recorded unless it exceeded that level.

In several cases, it was found necessary to change the threshold level. For example, a Dranetz Monitor on a 120 volt line was operated with a 50-volt threshold, and in the middle of the test effort that level was changed to 100 volts. This factor had to be taken into account during the data reduction effort.

When this occurred, the higher threshold was used in reducing the data for graphical presentation. As indicated in the analysis of Appendix B, this had the effect of displacing the resultant amplitude statistics, but did not change its shape.

---

[a]A limited number of tests were conducted at NESEA on transient coupling through single phase and 3-phase transformers, with the results informally provided to SFA.

## SECTION IV
## NICOLET DATA SUMMARY

### 4.1 GENERAL

Nicolet Model 2090-3 Digital Oscilloscopes were installed at all sites with the exception of the U.S. Naval Observatory and NAS Patuxent River. Due to malfunctions of the equipment, no data was available for NAS Oceana, Eglin AFB, Little Creek and Dam Neck. The Nicolet Oscilloscope is a wide band oscilloscope with digital sampling and magnetic disk storage and readout capability. It automatically records up to eight transient waveforms whose levels exceed a preset threshold. By replaying the stored transient waveform, the transient characteristics and a photograph of the waveform can be obtained. Because of its 10 MHz data bandwidths, the Nicolet provides a more accurate transient amplitude determination, and a method of obtaining transient pulse shape.

The Nicolet oscilloscopes capture no more than eight waveforms on a single disk, consequently not all transients which occurred while the instruments were connected to the power lines were recorded. The intent of utilizing the Nicolet recorders was not to verify the statistical distribution obtained by the Dranetz but to obtain an accurate representation of typical transients in order to classify the transients by measuring amplitudes, rise times, pulse durations and general waveform characteristics.

### 4.2 REPRESENTATIVE WAVEFORM ANALYSIS

Table 4-1 provides a summary of the 124 transients captured from NAS North Island, NAS Miramar and the Radar Site at St. Thomas. These sites were chosen to be a good representation of the transient waveforms detected. Each of the transients was matched with one of the nine categories identified in the table[1] to provide the data for the summary and to provide some weight into the nature of the most frequently occurring transient types.

---

[1]The categories were established when analyzing shipboard transients. See Sachs, H. and Ludford, J., op. cit.

TABLE 4-1

SUMMARY OF REPRESENTATIVE WAVEFORM DATA

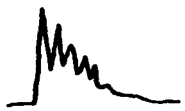
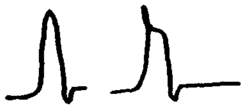
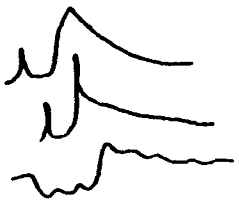
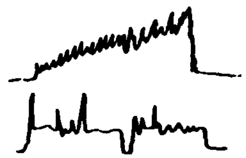
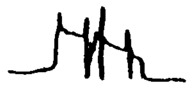
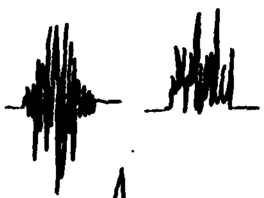
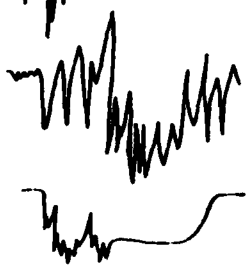
| TYPE | DESCRIPTION | WAVEFORM | PCT | ENCOUNTERED ON AC | ENCOUNTERED ON DC | AMPLITUDE RANGE (V) (on AC) | RISE-TIME RANGE (usec) | DURATION RANGE (usec) | OSC.FREQ. RANGE (kHz) |
|---|---|---|---|---|---|---|---|---|---|
| I | Spike with under-damped ringing |  | 11.6 | X | X | 52-398 | .05-80 | .6-1000 | 4.7-6667 |
| II | Similar to Type 1, but with more damping |  | 1.4 | X | | 124-152 | .2-2570 | 45-2570 | N/A |
| III | Spike or pulse in critically damped circuit |  | 48.9 | X | X | 104-2976 | 0.05-115 | 115-115 | N/A |
| IV | Similar to Type III but with superimposed oscillations |  | 3.2 | X | X | 544-848 | .15-94.7 | .3-.45 | All high-freq. oscillation |
| V | Spike with over-damping (some with ripple) |  | 1.4 | X | X | 280-1100 | .4-100 | 70.4-100 | N/A |

TABLE 4-1 CONT'D

SUMMARY OF REPRESENTATIVE WAVEFORM DATA

| TYPE | DESCRIPTION | WAVEFORM | PCT | ENCOUNTERED ON AC | ENCOUNTERED ON DC | AMPLITUDE RANGE (V) (on AC) | RISE-TIME RANGE (usec) | DURATION RANGE (usec) | OSC.FREQ. RANGE (kHz) |
|---|---|---|---|---|---|---|---|---|---|
| VI | Slow overdamped transient with superimposed noise. |  | 0 | | | N/A | N/A | N/A | N/A |
| VII | Pulse transient with superimposed noise. |  | 1.4 | X | | 51-56 | 1 | 344-900 | N/A |
| VIII | Noise Burst |  | 22.8 | X | X | 60-640 | .2-2 | .15-71 | N/A |
| IX | Miscellancous |  | 9.3 | X | X | 72-312 | 19.6-11,000 | 125-11,000 | N/A |

Actual photographs of representative transients from each of these locations are displayed below in Figures 4-1, 4-2 and 4-3. Although representative, the photographs do not convey the full range of transients which occurred at each site, nor necessarily the typical or "average" transient, since recordings of each transient which occurred during the time in which the sites were visited were not obtained.

## 4.3 AMPLITUDE STATISTICS

As stated previously, only a relatively small amount of Nicolet Oscilloscope data was accumulated during this study, compared to the amount of Dranetz data recorded. Nevertheless, invaluable information was obtained concerning the nature and characteristics of shore-station transients.

Table 4-2 augments the Nicolet transient statistics presented previously in Table 2-14. Upon comparing the amplitude statistics in this table for the St. Thomas antenna location with Dranetz statistics for the same location (see Table 2-9), an apparent inconsistency is observed. The Nicolet statistics for this location cite a calculated voltage average of 1262 volts and a recorded peak transient of 2976 volts, in contrast to the 840-volt maximum peak amplitude recorded by co-located Dranetz equipment.

The apparent lack of peak amplitude correlation between the two measurement devices may be explained by the impulse response limitations of the Dranetz recorder. The Dranetz Analyzer is designed for use with transients having a minimum excursion of 0.5 μsec. Although calibaration tests of the Dranetz equipment were not made below 0.5 μsec. indications were that amplitude accuracy began to fall off below 1 μsec and significantly lower than actual levels could be expected at 0.5 μsec[1].

The high-level transients that were recorded on the Nicolet device were characterized by short impulse duration times, typically 0.3 μsec. As a result it would not be surprising to discover that many large-amplitude transients

[1] ibid, Figure 4-5.

AD-A115 707 SACHS/FREEMAN ASSOCIATES INC BOWIE MD F/G 10/2
INVESTIGATION OF SHOREBASED POWERLINE TRANSIENTS. PHASE II.(U)
SEP 81 N00421-79-C-0183
UNCLASSIFIED NL

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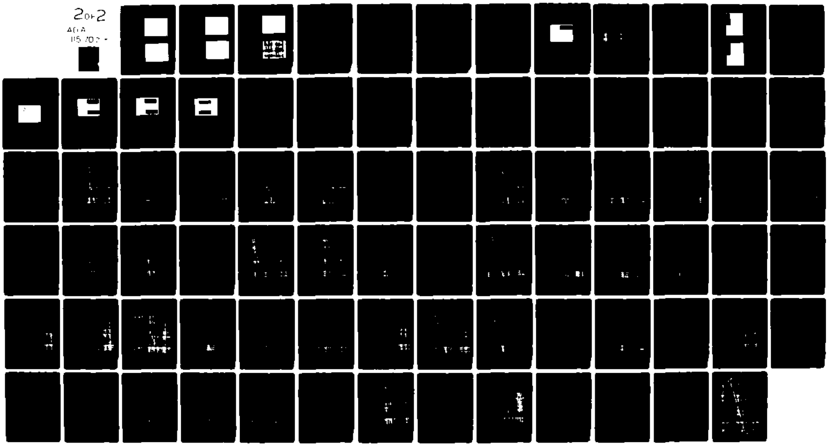
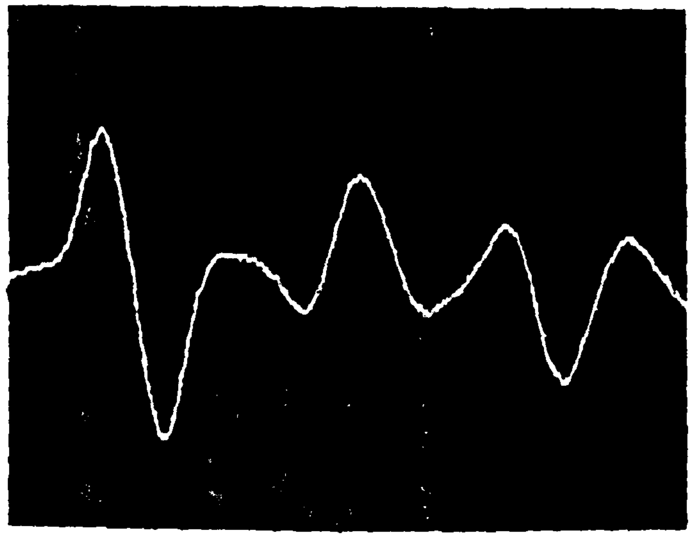


FIGURE 4-1
NAS NORTH ISLAND

(a) Location: Bldg. #335
2500 amp Panel

Max. Amplitude: +280V
-304V

Rise Time: .18 milliseconds
Duration: 2.3 milliseconds



(b) Location: Bldg. #335
2500 amp Panel

Max. Amplitude: +152V
- 88V

Rise Time: 6 microseconds
Duration: 45 microseconds

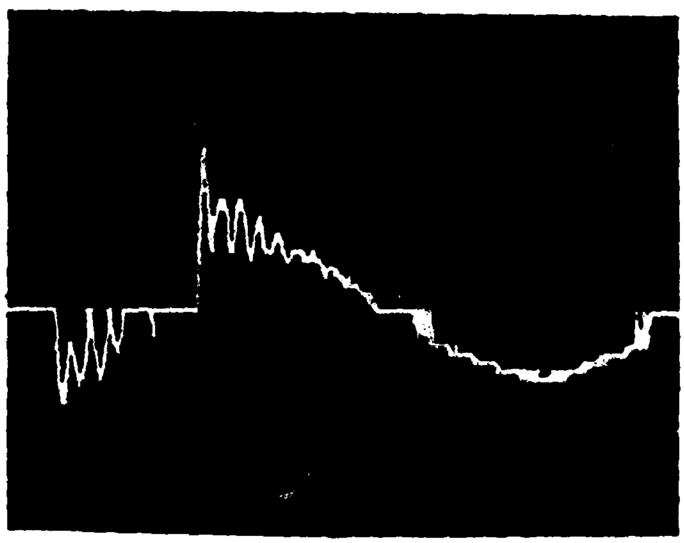


FIGURE 4-2

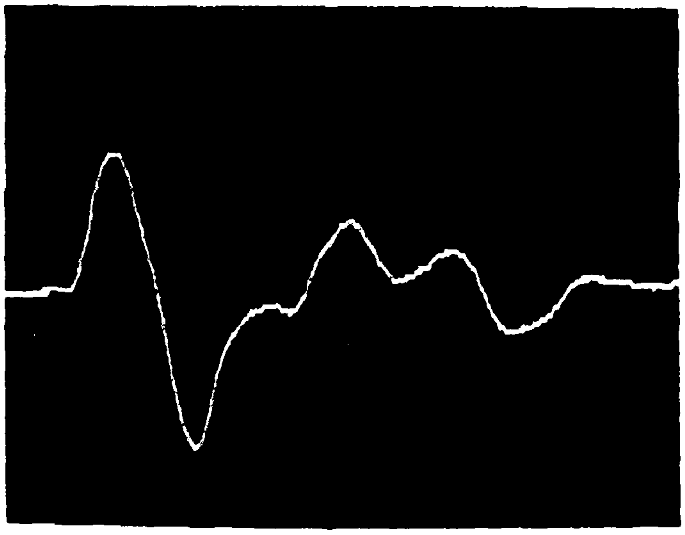
NAS MIRAMAR

(a) Location: Facility Wall Box

Max. Amplitude: +52.8V
-59.2V

Rise Time: 34 microseconds
Duration: 730 microseconds

Osc. Frequency: 5.5 KHz



(b) Location: Facility Wall Box

Max. Amplitude: +70V
-89.6V

Rise Time: 1 microsecond
Duration: 71.0 microseconds

Osc. Frequency: 2.3 MHz

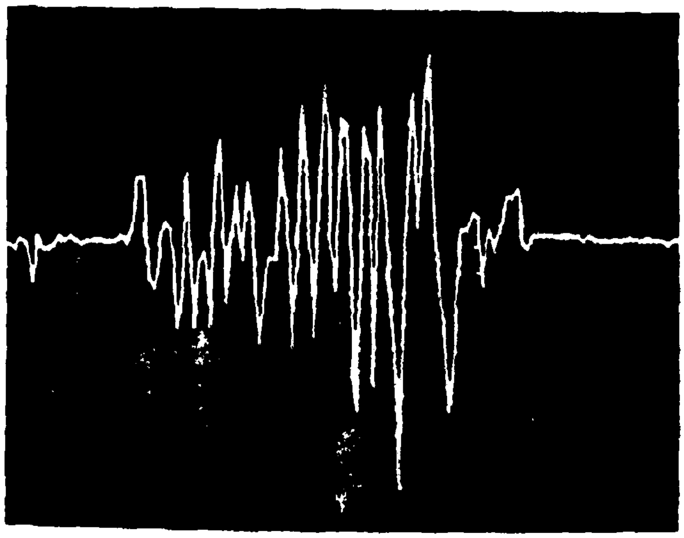


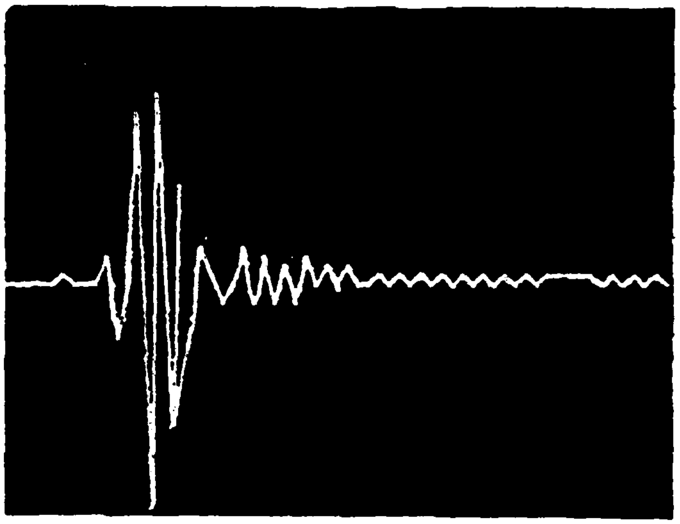
FIGURE 4-3
RADAR SITE ST. THOMAS ISLAND

(a) Location: "Source"
Side of Distribution

Max. Amplitude: -160V
+134.4V

Rise Time: .1 microsecond
Duration: 1.0 microsecond

Osc. Frequency: 9.0 MHz



(b) Location: "Source"

Max. Amplitude: 1004.8V

Rise Time: .2 microseconds
Duration: .35 microseconds

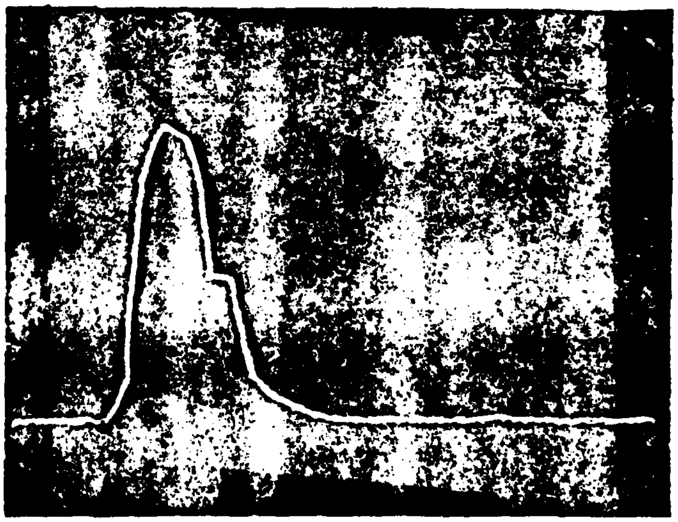


TABLE 4-2

NICOLET TRANSIENT STATISTICS SUMMARY

| Location | Voltage Level | Maximum Voltage | Average Voltage | Average Rise Time(us) | Average Duration(us) |
|---|---|---|---|---|---|
| NAS North Island | 120V AC | 312 | 156.3 | 98.2 | 1311 |
| NAS Miramar | 120V AC | 89.6 | 60.7 | 22 | 630 |
| St. Thomas Radar Site | | | | | |
| Source | 120V AC | 1504 | 365.4 | 1.18 | 4.6 |
| Source (Current) | 120V AC | 16.8 Amp | 3.3 Amp | .12 | 2.6 |
| Load | 120V AC | 73.6 | 68.5 | 1.04 | 14.5 |
| Antenna | 120V AC | 2976 | 1262 | 2.02 | 3.91 |

TABLE 4-2 CONT'D

NICOLET TRANSIENT STATISTICS SUMMARY

| Location | Voltage Level | Maximum Voltage | Average Voltage | Average Rise Time(us) | Average Duration(us) |
|---|---|---|---|---|---|
| NAS Key West, FL | | | | | |
| Soc Room Power Panel | 120V | 88 | 61 | 2.008 | 37.01 |
| FAA Radar Tower (FPS-67) | 120V | 117 | 84 | 4.25 | 10.85 |
| Main Generator Room | 460V | 74 | 68 | 2.2 | 7.3 |
| TACAN Site | 120V | 240 | 204 | 1.8 | 19.6 |
| ASW Training Center Norfolk, VA Bldg. L-28, Room 43 | 120V | 206 | 128.5 | 1.34 | 17.86 |

TABLE 4-2 CONT'D

NICOLET TRANSIENT STATISTICS SUMMARY

| Location | Voltage Level | Maximum Voltage | Average Voltage | Average Rise Time(us) | Average Duration(us) |
|---|---|---|---|---|---|
| San Juan, PR | | | | | |
| Antenna Power Panel | 120 | 86 | 71 | .6 | 1.0 |
| Generator Room Power Panel | 120 | 155 | 128.5 | .3 | 0.7 |
| NAVCOMSTA, Diego Garcia | | | | | |
| B-10-T | 280 | 344 | 209.5 | 3.28 | 4.45 |

were not recorded as large-amplitude transients by the Dranetz monitors as a result of the minimum 0.5 μsec excursion duration restriction.

The 2976-volt transient recorded at the Radar Antenna location and shown in Figure 4-4 was of obvious concern to the NESEA personnel conducting these measurements, especially since component damage actually occurred as a result of this disturbance. An attempt was made by NESEA experts to locate the source of this and other high-power transients occurring at this location, by tracing these excursions point-by-point back to their source. It was determined by NESEA personnel that these transients occurred "in-house" as a result of the induction field collapse of two drive motors which caused arcing across the antenna drive motor contactor contacts; transformer isolation was suggested to reduce or eliminate future damage.

Figures 4-5 and 4-6 depict the transient peak amplitude distribution for the combined 120V data obtained at the seven Nicolet-monitored sites. The data is displayed on log-log paper in Figure 4-5 and on probability paper in Figure 4-6. A near-linear distribution is observable on the probability paper, indicating a near-normal distribution for this data.

## 4.4 ENERGY STATISTICS

Portions of the oscilloscope data obtained from the Nicolet-instrumented sources consisted of simultaneously monitoring voltage and current transient excursions. This information was used to calculate the energy present in these pulses. The mathematical technique used to compute this energy is described in the previously-referenced Phase I report.[1] The two transients containing the largest amount of energy are described here. They were both recorded at the Source connection at the St. Thomas Radar Site.

Figure 4-7 depicts the voltage and current waveforms recorded for one of these transients. As shown, the peak voltage at this transient is 1005 volts

[1] ibid

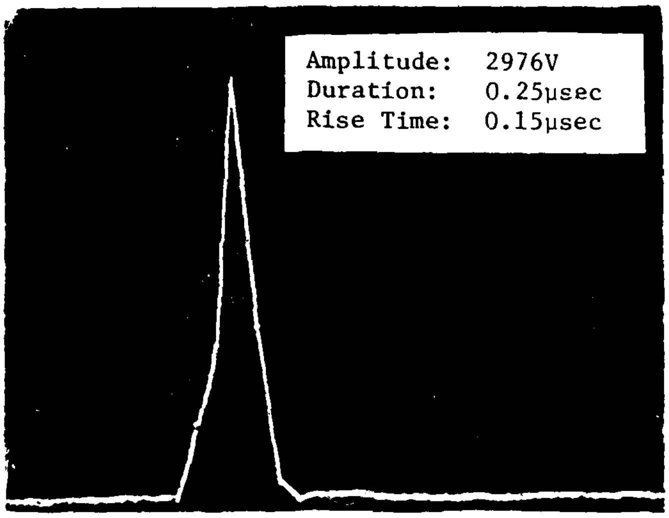



Figure 4-4. High-Voltage Waveform Recorded at St. Thomas Radar Antenna Location

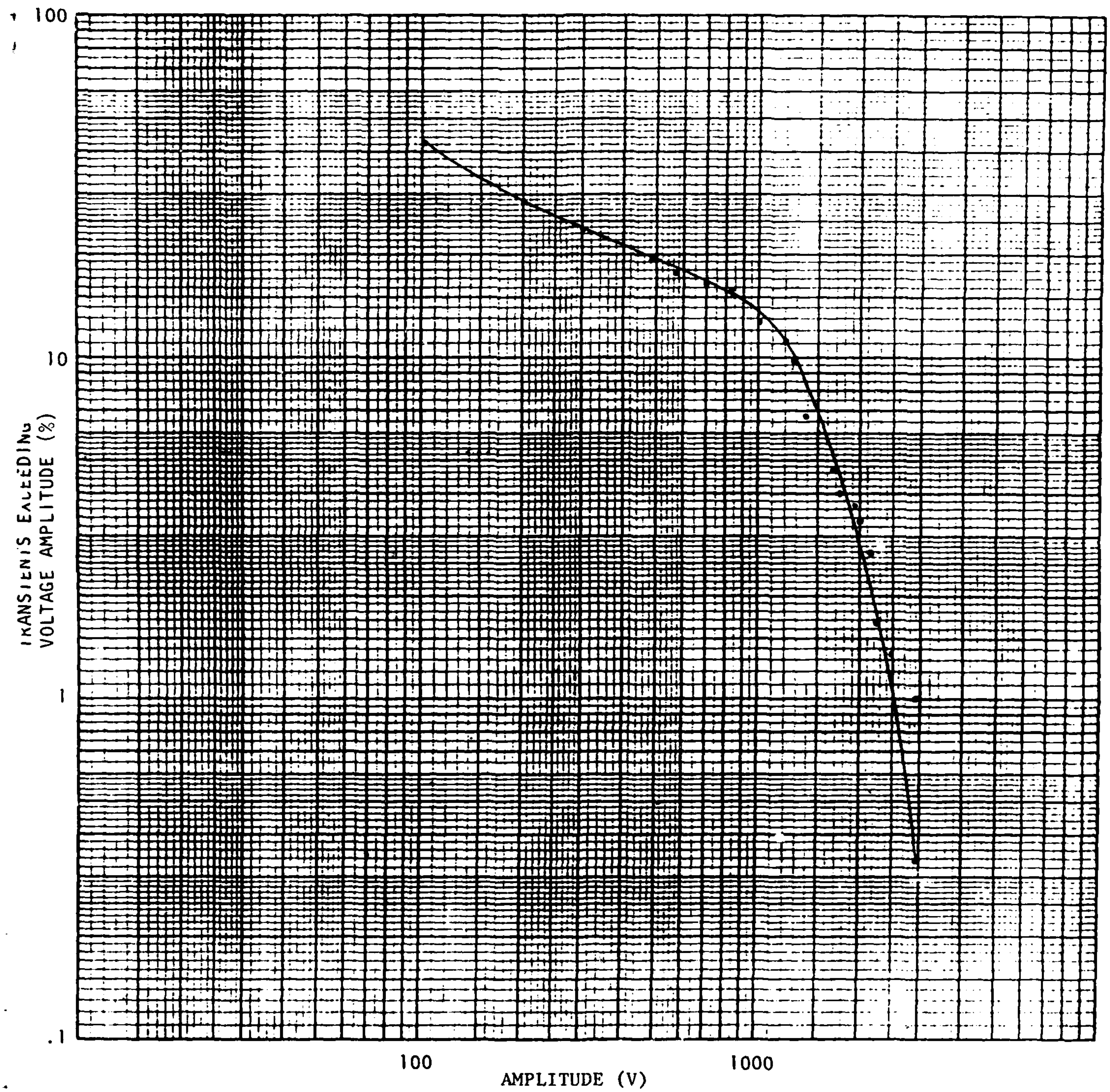


Figure 4-5. Peak Amplitude Distribution
For Combined 120V
Nicolet-Recorded Transients

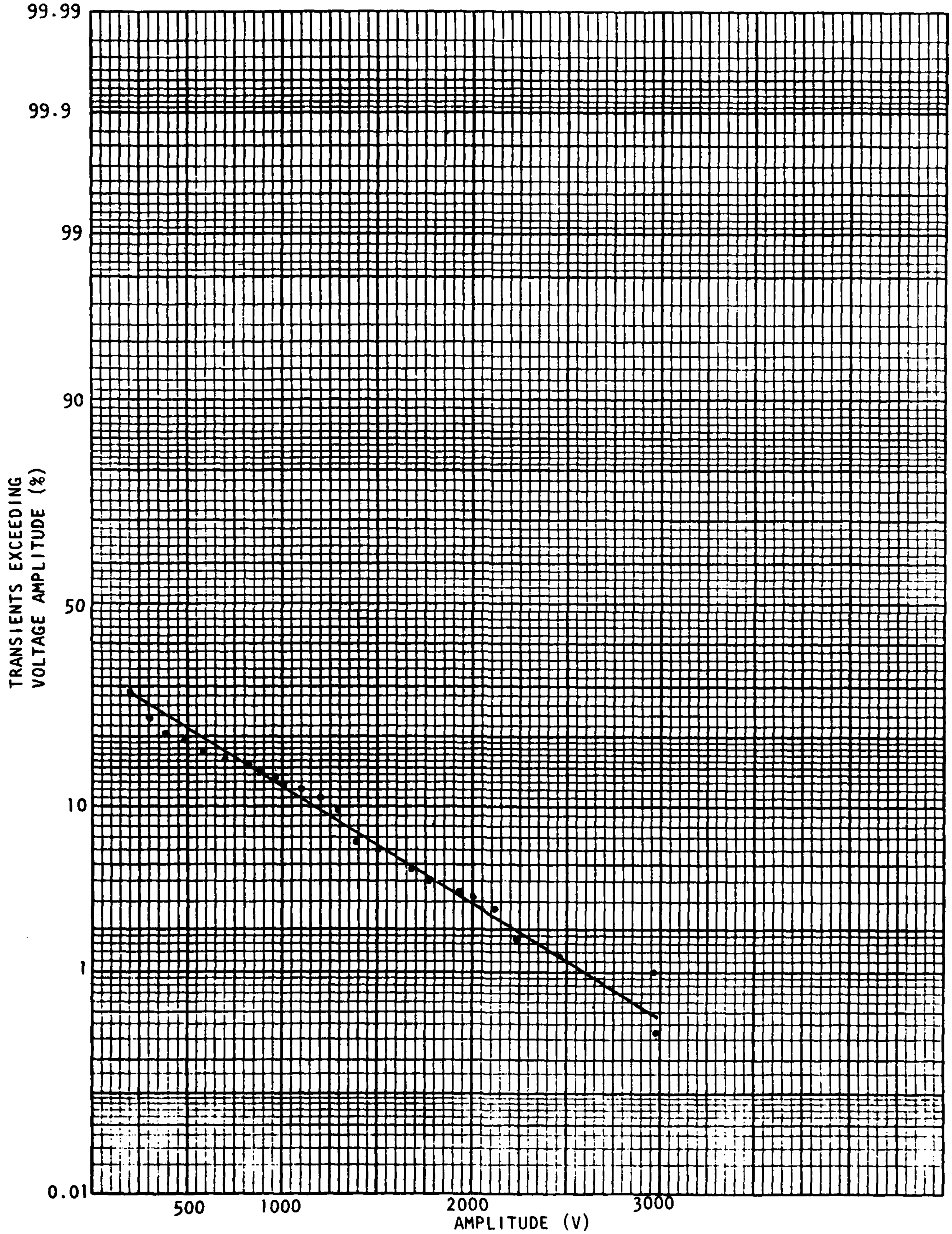
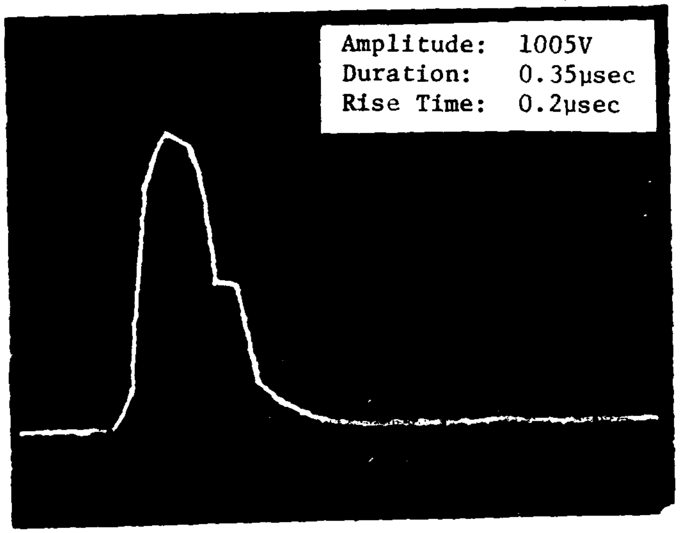
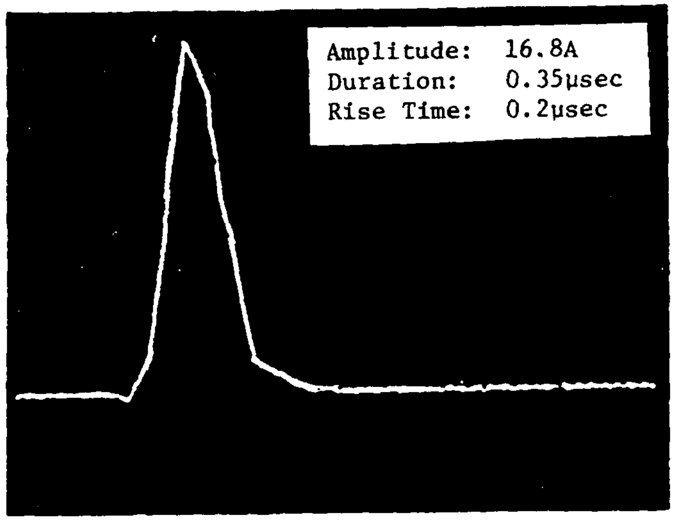



Figure 4-6. Peak Amplitude Distribution For Combined 120V Nicolet-Recorded Transients




VOLTAGE




CURRENT

Figure 4-7. Voltage and Current Waveforms for First Sample High-Voltage Transient.

and the peak current is 16.8 amperes; the pulse duration was 0.35 μsec. The total energy calculated for this pulse was 1.7 millijoules. The other transient pulse is shown in Figure 4-8. The voltage and current peaks recorded for this transient were 1500 volts and 8.2 amperes, respectively; the time length of the pulse was 0.4 μsec. The resultant energy calculated for this pulse was 1.9 millijoules. In contrast, the highest transient energy encountered during the shipboard transient portion of this effort was 4.2 microjoules.

## 4.5 DC TRANSIENT BEHAVIOR

At the St. Thomas Radar Site a 5-volt dc buss and a 20-volt dc power supply output were periodically monitored simultaneously with the ac power line at the radar antenna location. Transients at both dc locations occurred concurrently with ac transients at the radar antenna. Figures 4-9, 4-10 and 4-11 depict this disturbance correlation.

Figure 4-9 shows the coincident transient occurrence at the Antenna location and 5-volt dc buss. As observable in this figure, high-voltage ac transients can have significant effects on dc output points. The transient occuring at the 5-volt dc buss in this case was almost twice the normal dc line voltage.

Figure 4-10 depicts coincident transients at the Antenna location and the 20-volt dc power supply at St. Thomas.

Figure 4-11 was recorded for the same locations as Figure 4-10 but for a lower-amplitude transient.

VOLTAGE TRANSIENT

Amplitude: 150V
Duration: 0.4μsec
Rise Time: 0.15μsec

CURRENT TRANSIENT

Amplitude: 8.2A
Duration: 0.4μsec
Rise Time: 0.15μsec

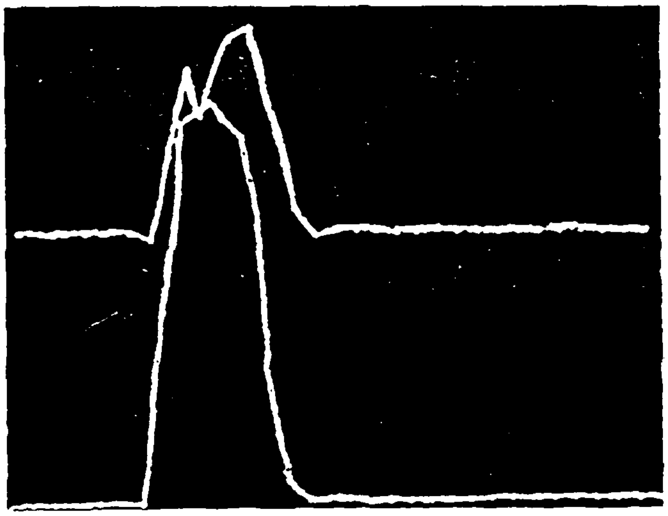



Figure 4-8. Voltage and Current Waveforms for Second Sample High-Energy Transient.

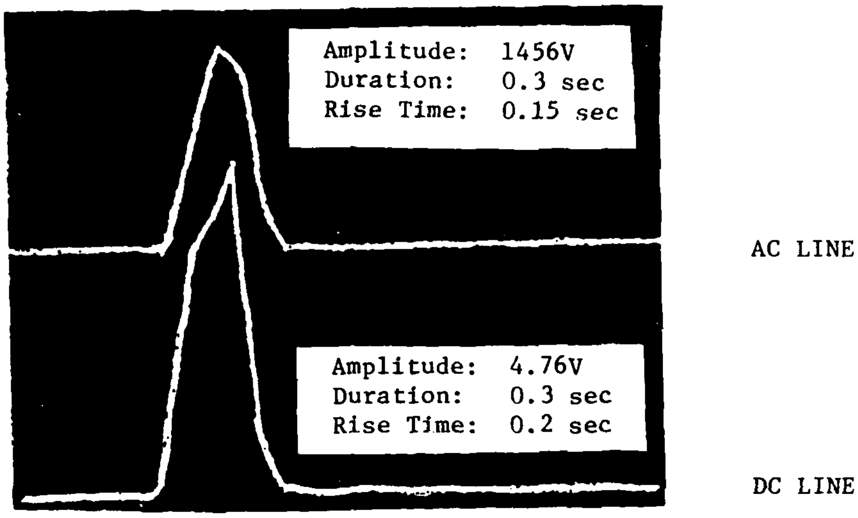



Figure 4-9. Coincident transients at the St. Thomas Radar Antenna Location and 5 volt DC Buss.

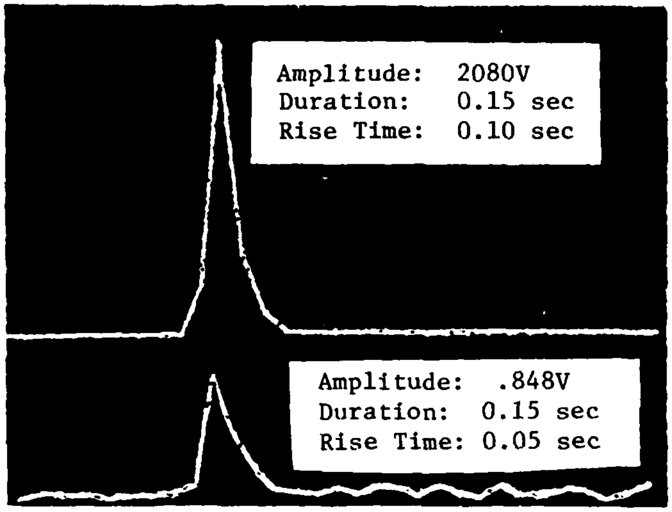



Figure 4-10. Coincident transients at the St. Thomas Radar Antenna Location and 20 volt DC Power Supply.

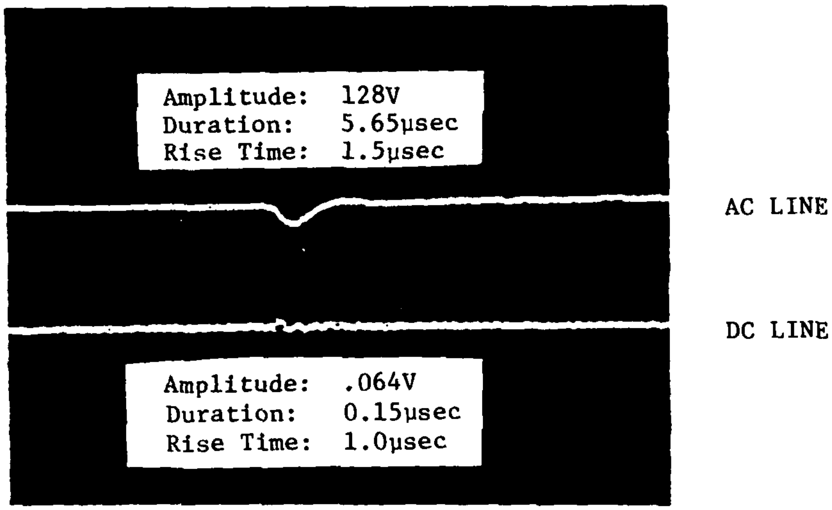



Figure 4-11. Coincident transients at the St. Thomas Radar Antenna Location and 5-volt DC Buss; Low-voltage case.

## SECTION V

## COMPOSITE DATA SUMMARY

### 5.1 GENERAL

It is of interest to combine all of the shorebased 120 volt transient amplitude data collected on this program, including both Dranetz and Nicolet measurements. This has been done in Figure 5-1, which is a graph plotted on normal probability paper. In this figure, Curve I represents these combined amplitude statistics.

Curve I exhibits a trend similar to that found in earlier reported shipboard data; the amplitude distribution above a particular amplitude level (in this case, above about 300 volts) follows a normal distribution. In fact, the statistics seem to be piecewise linear, with the data below 300 volts following a straight line as well.

Curve I represents 114,242 hours of transient monitoring. This converts to a transient rate of about 0.22 transients per hour.

Based on the curve, it can be concluded that the likelihood of certain transient levels occurring in a one year period are as follows:

| Transient Amplitude (Volts) | Number of Transients Expected to Occur in a 1 Year Period |
|---|---|
| 2700 | .2 |
| 1700 | 1 |
| 1200 | 2 |
| 550 | 6 |

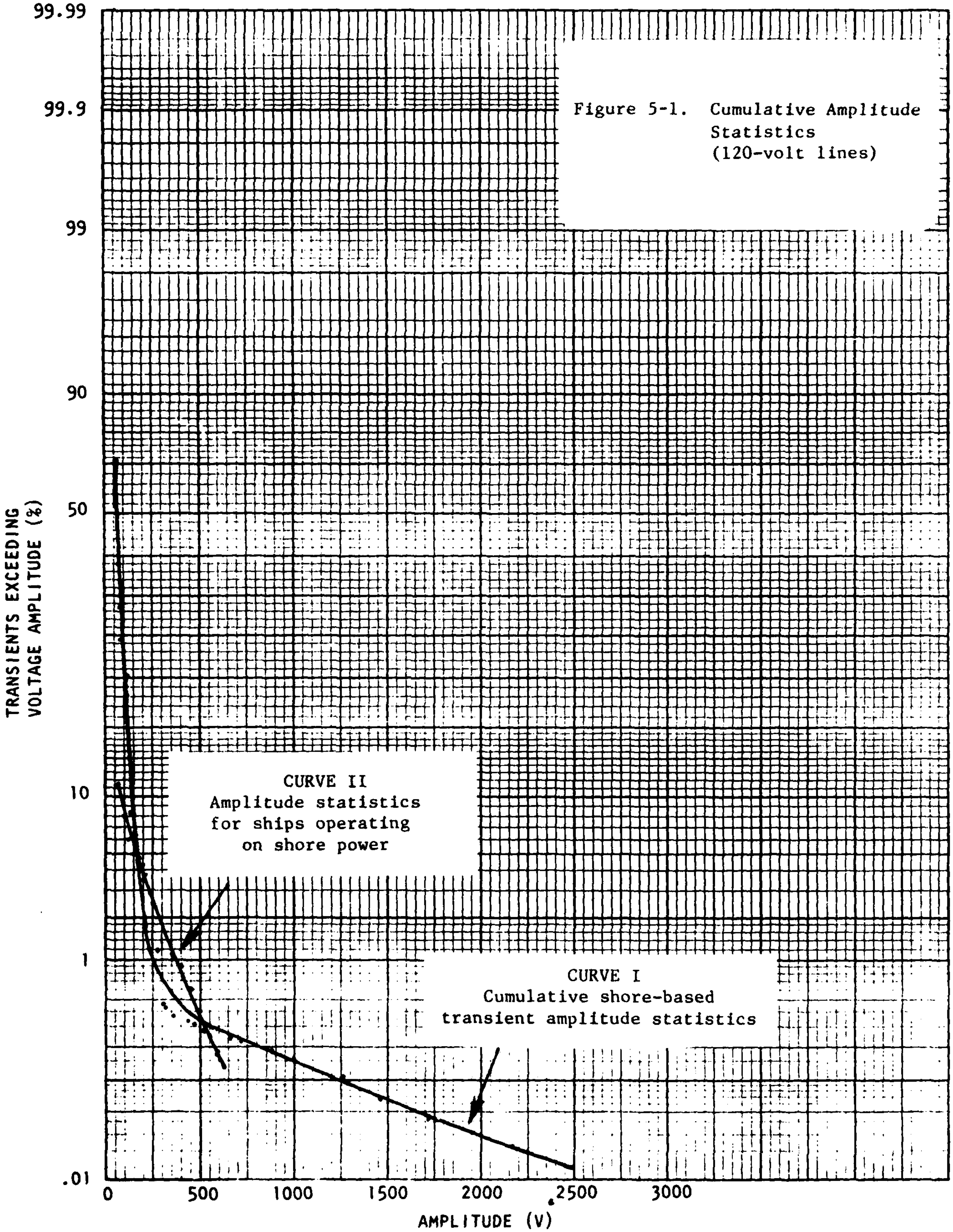


Figure 5-1. Cumulative Amplitude Statistics (120-volt lines)
CURVE II
Amplitude statistics for ships operating on shore power
CURVE I
Cumulative shore-based transient amplitude statistics
TRANSIENTS EXCEEDING VOLTAGE AMPLITUDE (%)
99.99
99.9
99
90
50
10
1
.01
0
500
1000
1500
2000
2500
3000
AMPLITUDE (V)

## 5.2 COMPARISON WITH EARLIER DATA

The earlier shipboard transient study determined the amplitude statistics of transients occurring when the ships involved were in port and connected to shore power.[1] Those statistics are also plotted in Figure 5-1 for comparison purposes (Curve II). While the likelihood of transients occurring in the 150-600 volt amplitude range are similar, it is clear from this comparison that higher amplitude transients occurred at the sites covered by this report.

As noted earlier, the high level transients at the shore stations considered in this report had relatively narrow durations (≈0.3 μsec.). This is in contrast to both the ship and shore-power data collected during the shipboard tests, where such narrow duration, high-amplitude pulses were rare.

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[1] ibid., Figure 4-7

## SECTION VI

## CONCLUSIONS AND RECOMMENDATIONS

### 6.1 CONCLUSIONS

This report provides a detailed analysis of perhaps the most extensive amount of data ever collected on power-line transients at Navy shore facilities. This involved over 134,700 hours of power line monitoring, during which approximately 27,500 transients were recorded. About 94% of the data was accumulated using Dranetz Power-Line Disturbance Monitors, and the remaining 6% was obtained with Nicolet Digital Oscilloscopes.

A number of conclusions may be derived directly from the transient data analysis. These are summarized as follows:

a. Although four line-voltage configurations were monitored at one time or another in the course of this effort, namely 120-volt line-to-ground, 120-volt line-to-line (208V), 280-volt and 460-volt power lines; 88% of the data was recorded on 120-volt lines in the line-to-ground or common mode, the mode for which the results of this analysis may best be applied.

b. Among the thirteen shore facilities visited, the extent to which transients occurred varied considerably. The highest transient rates were found at specific locations at NAS Key West, FL and the Anti-Personnel Intrusion Test Site, Eglin AFB, FL, corresponding to almost two transients/hour. However, the highest level transients occurred at The St. Thomas Radar Site, VI on the power-line feeding the antenna drive system.

c. On Dranetz equipment, a peak transient amplitude maximum of 872 volts was recorded on 120-volt lines, while an 1184-volt transient maximum was recorded on 460-volt lines. Both of these transient maxima occurred at NAS Oceana, VA.

d. The Nicolet equipment, which was employed on 120-volt lines, recorded a maximum transient amplitude of 2976 volts at the St. Thomas, VI Antenna Location.

e. In general, higher transient amplitudes were recorded on Nicolet equipment than on Dranetz. A contributing factor to this phenomenon may be the minimum 0.5 μsec impulse duration limitation for the Dranetz device. Most of the higher level transients recorded by Nicolet Oscilloscopes had pulse durations of approximately 0.3 μsec.

f. For the composite Dranetz statistics, approximately 53% of all the transients recorded had peak amplitudes between 50 and 100 volts, 46% had amplitudes between 100 and 500 volts, and 0.1% were recorded with amplitudes between 500 and 1000V; less than 0.01% of these occurred with amplitudes greater than 1000 volts.

g. Most of the cumulative probability distribution functions calculated for the various locations and sites exhibited a linear distribution when plotted on log-log paper. However, when the composite 120-volt site statistics were compiled, the cumulative probability density function exhibited a linear distribution when plotted on probability paper, signifying a normal distribution of the composite 120-volt data.

h. Although a limited amount of Nicolet data was collected in comparison with the amount of Dranetz data, significant information was obtained with respect to the rise time, pulse duration, transient energy; etc., which was not obtainable from the Dranetz statistics.

i. The highest energy level encountered on transients measured with Nicolet Oscilloscopes located at the shore facilities was 1.9 millijoules; this is in contrast to the Phase I shipboard report, for which the maximum shipboard transient energy encountered was 4.2 microjoules. This should not be construed as implying that shore-based transients contain more energy than their shipboard counterparts, since the data sampling was fairly limited in both cases.

j. Ac transients can have significant effects on dc power lines; in one situation encountered during this study, a transient of almost twice the dc line voltage occurred concurrently with a recorded ac transient.

k. Much higher level transients were observed during this investigation than were encountered as part of the shipboard effort (including ships operating from shore power). However, the cumulative statistics in both cases conformed to normal distributions.

l. Based on a limited amount of data involving transient behavior on both the primary and secondary sides of isolation and step-down transformers, it appears that transformers act as fair transient suppression devices. It was not uncommon to find a transient on one side of the transformer not being of sufficient level to be recorded on the other side of the transformer.

## 6.2 RECOMMENDATIONS

Based on the conclusions set forth above, the following recommendations are made:

a. It is recommended that this report be used as the basis for modifying MIL-STD-461 ( ) to reflect the high amplitude, narrow duration shorebased transients.

b. It is recommended that additional shorebased tests be performed that provide simultaneous voltage and current waveform measurements for determining transient energy content. Present data is not of sufficient quantity to establish statistical validity on transient energy levels.

c. In view of the fact that most high amplitude transients were of short duration (0.3 μsec or less), it is recommended that additional tests be performed to determine the extent to which the bandwidth limitations of the Dranetz 606-3 and Nicolet 2090-3 affected the results obtained. To do this it will be necessary to employ a wider bandwidth non-sampling storage oscilloscope at the shore facility, and to take scope photographs directly. Equipment to do this is readily available.

d. It is recommended that additional testing of the effects of transformers on transients be performed, so that quantitative indications of transformer transient suppression can be obtained.

e. Finally, it is recommended that a Nicolet Model 446A Fast Fourier Transform (FFT) Computing Spectrum Analyzer be added to the test instrumentation with the Nicolet Model 3090-3 Digital Oscilloscope to compute and display frequency spectra for current and voltage transient waveforms. The spectral data can then be used to compute power line impedance as a function of frequency.

## APPENDIX A

## LOCATION TRANSIENT AMPLITUDE DISTRIBUTIONS

The cumulative complementary distributions for the transient peak amplitudes occurring at most of the locations examined during this effort are provided in this appendix as Figures A-1 through A-53. Several locations are not included here because of an insufficient number of recorded transients for those locations. Also provided in the upper right hand corner of each figure are the equations that describe the curves which are shown.

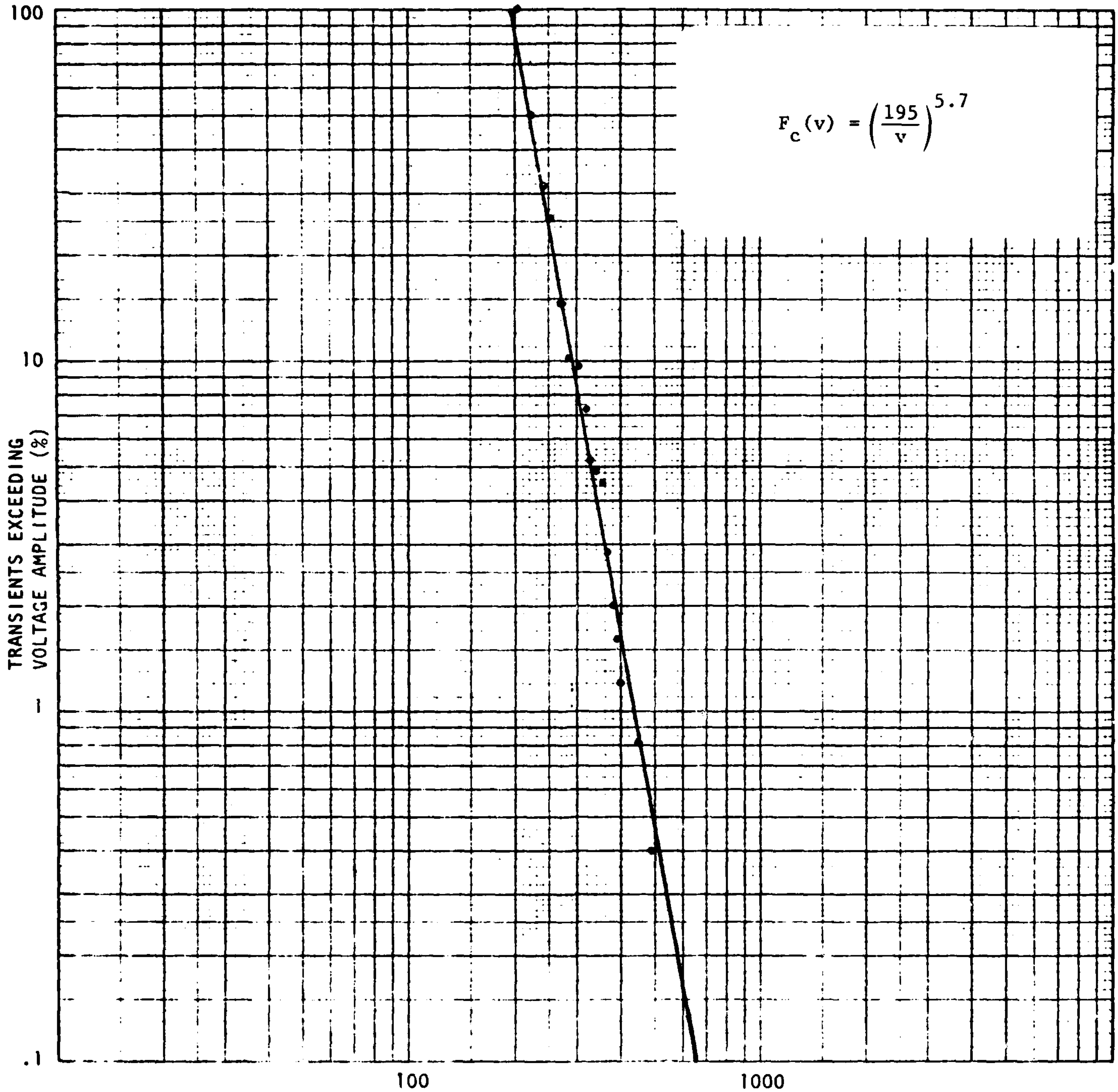


Figure A-1. Peak Amplitude Distribution
Main Generator Power Panel (460V)
NAS Key West, FL

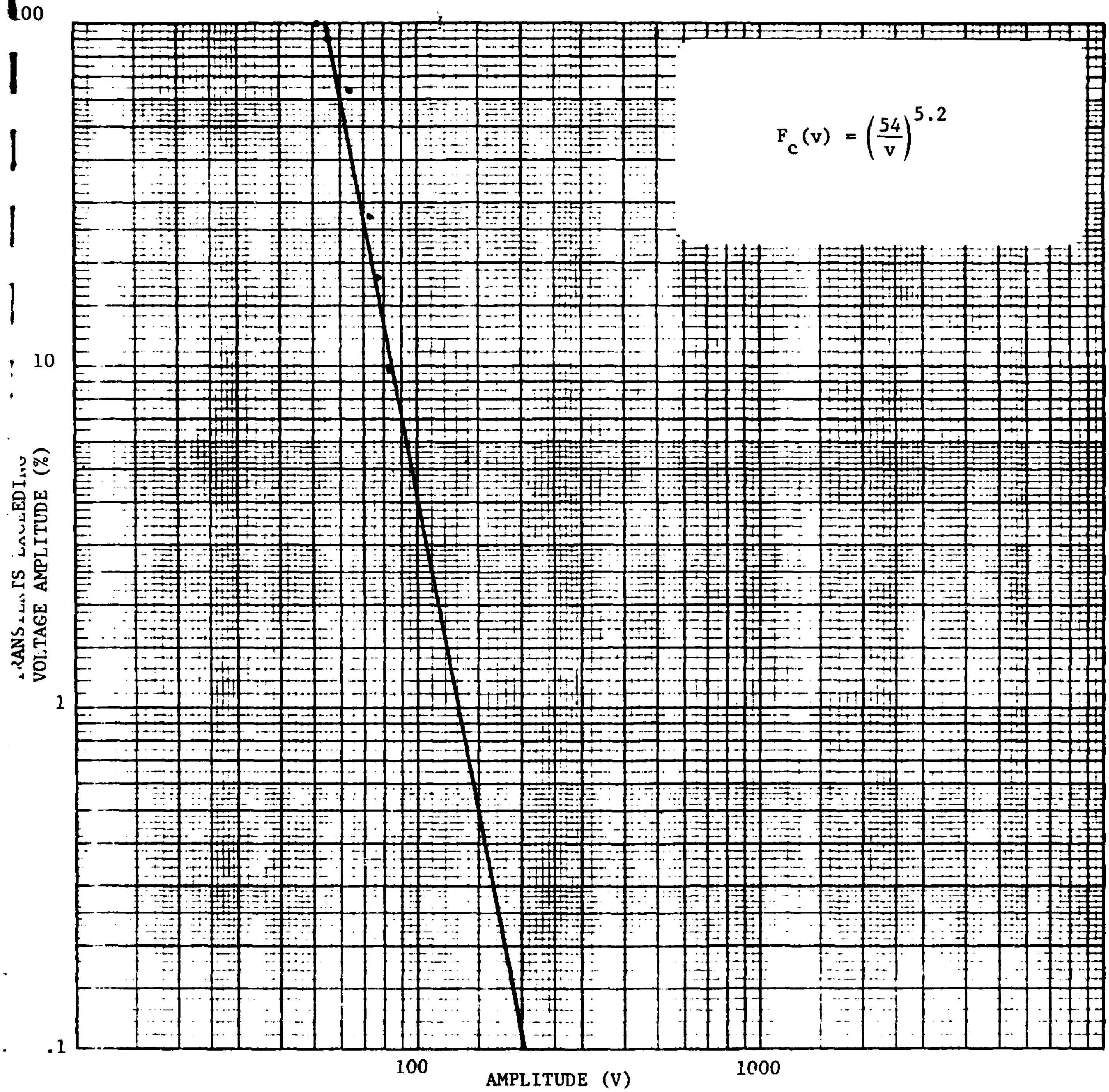


Figure A-2. Peak Amplitude Distribution
SOC FPS 6A Air Conditioner Power Panel (120V)
NAS Key West, FL

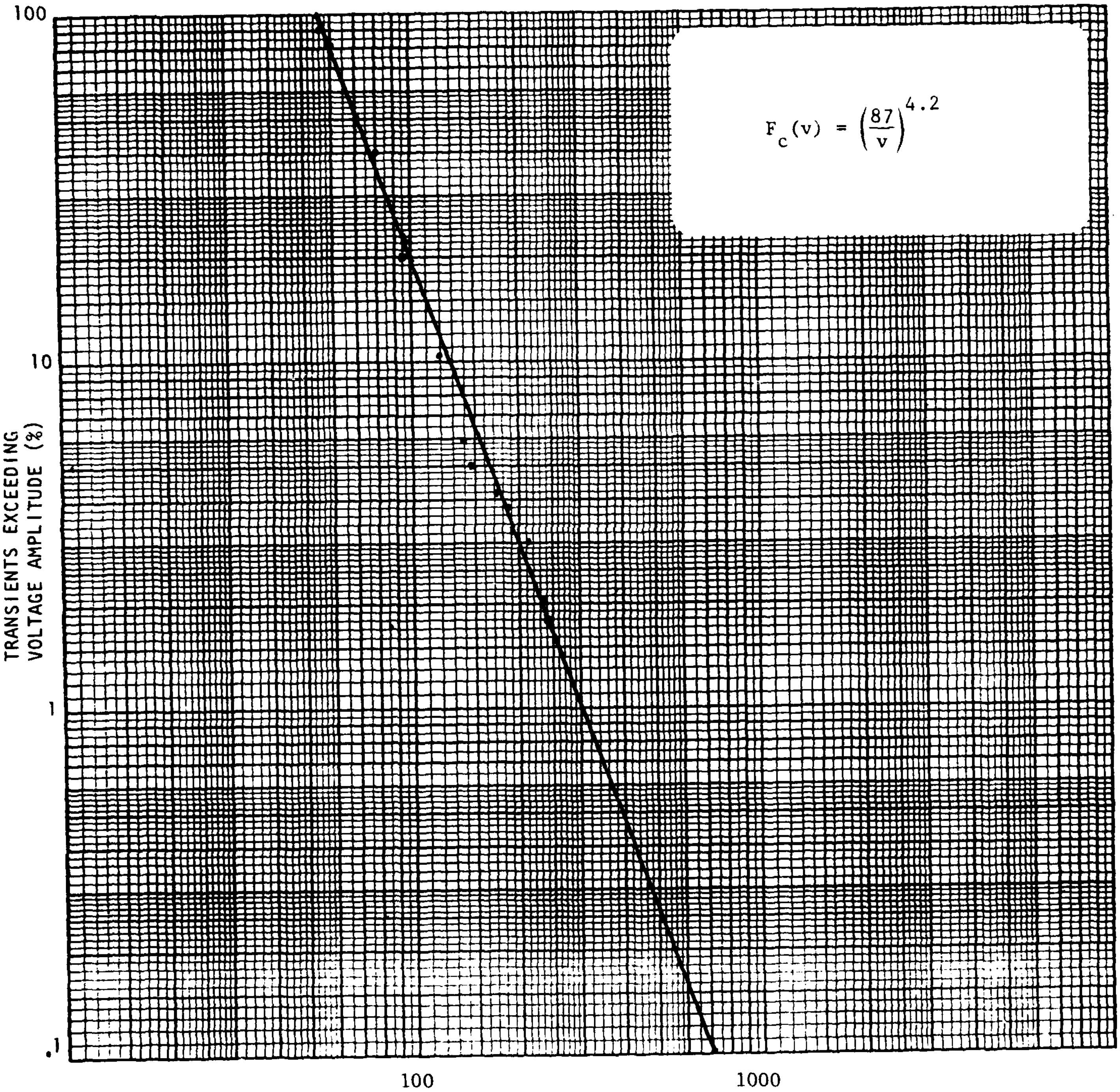


Figure A-3. Peak Amplitude Distributors
SOC Room Power Panel (120V)
NAS Key West, FL

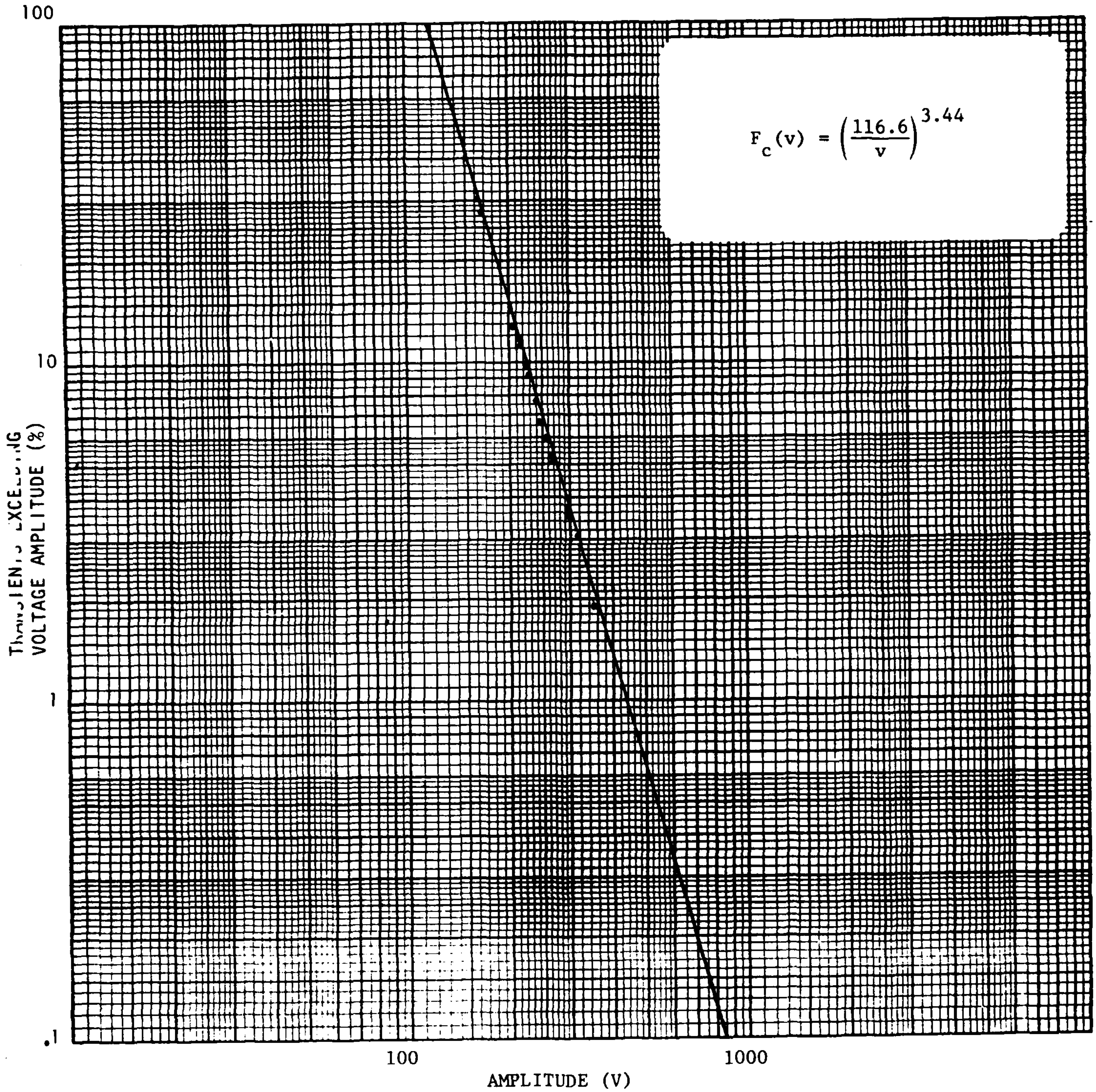


Figure A-4. Peak Amplitude Distribution
UPA-35 Power Panel (120V)
NAS Key West, FL

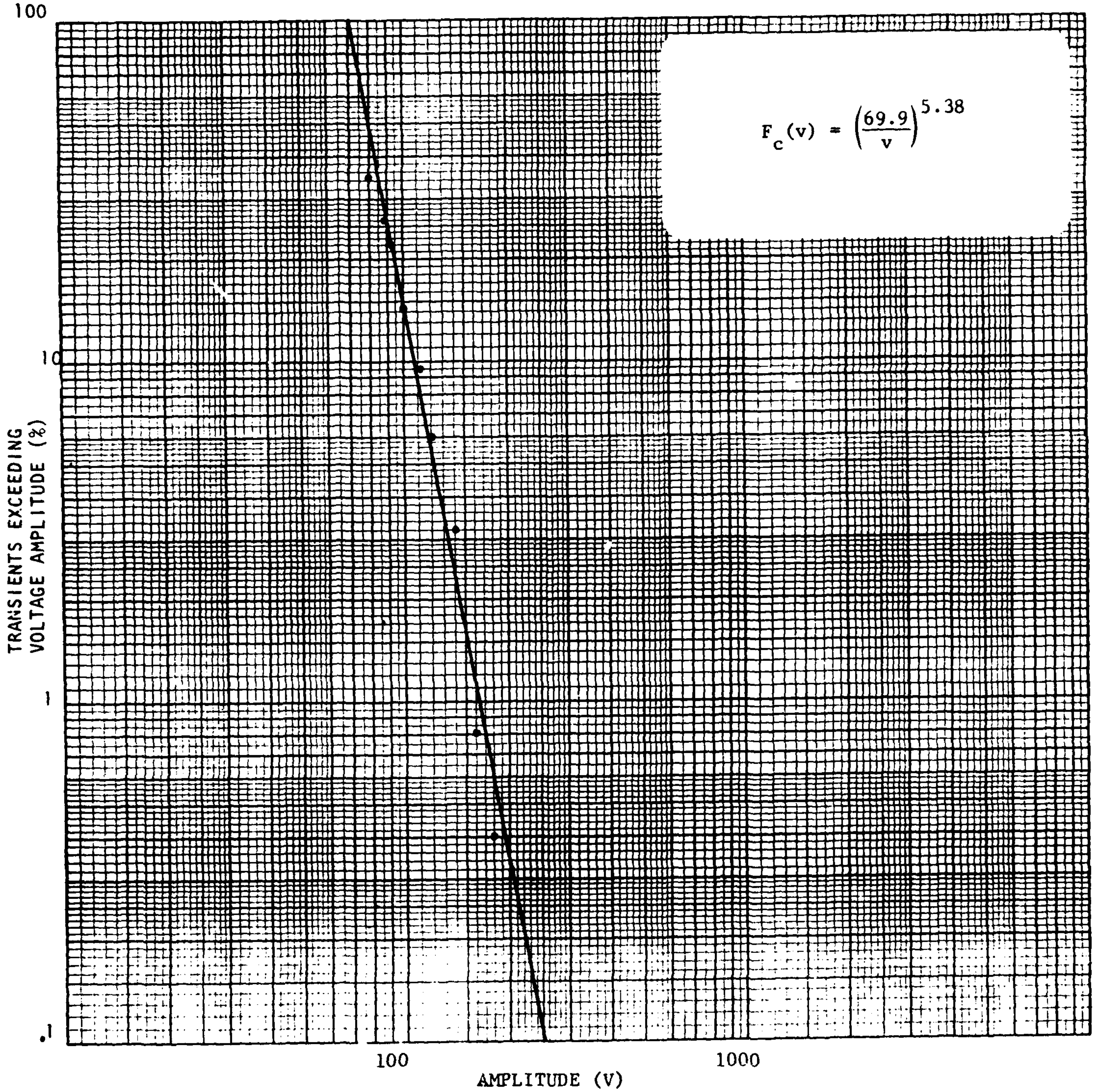


Figure A-5. Peak Amplitude Distribution
Generator Trailer (120V)
NAS Key West, FL

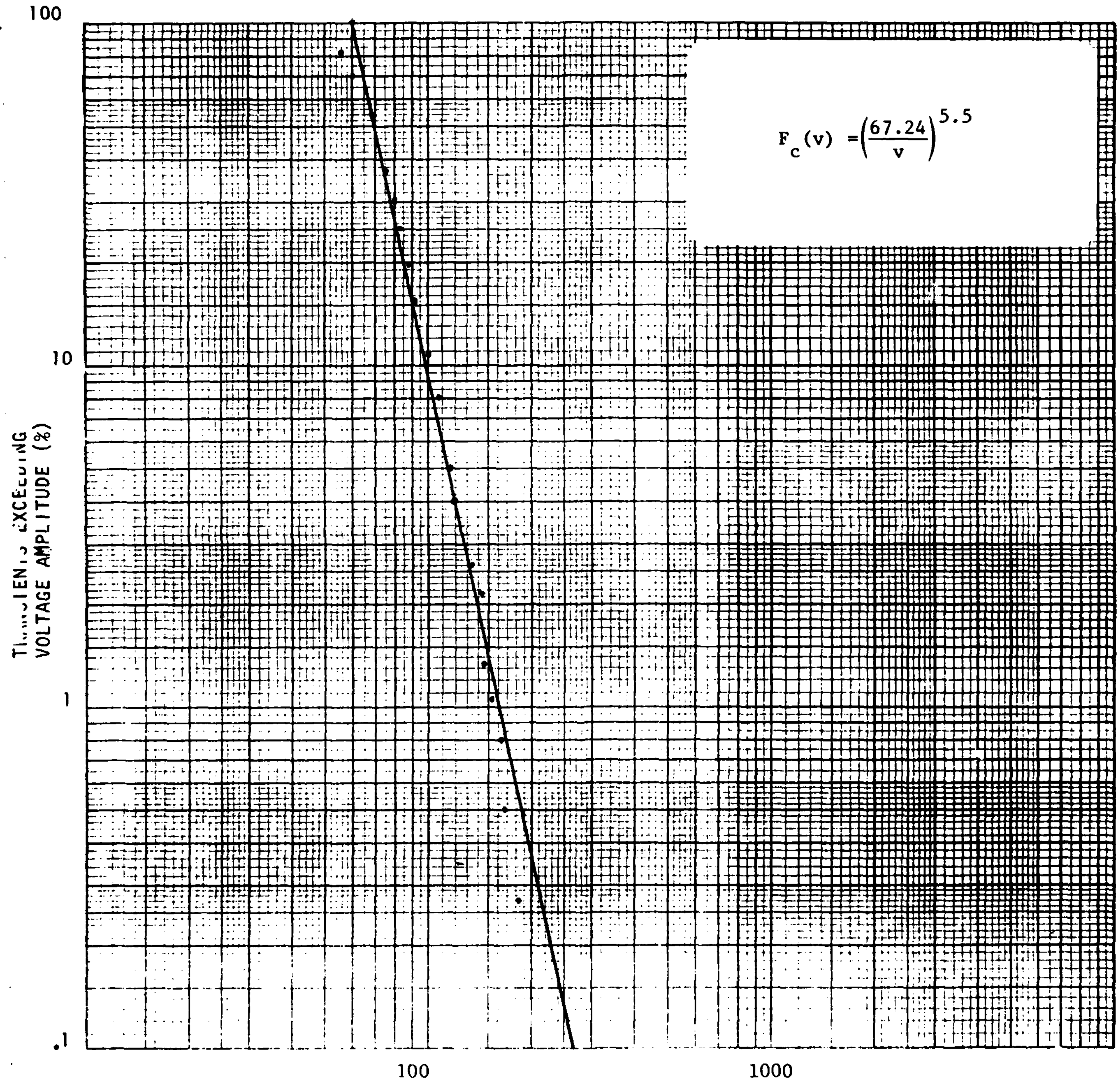


Figure A-6. Peak Amplitude Distribution
Radar Tower (FPS-67) (120V)
NAS Key West, FL

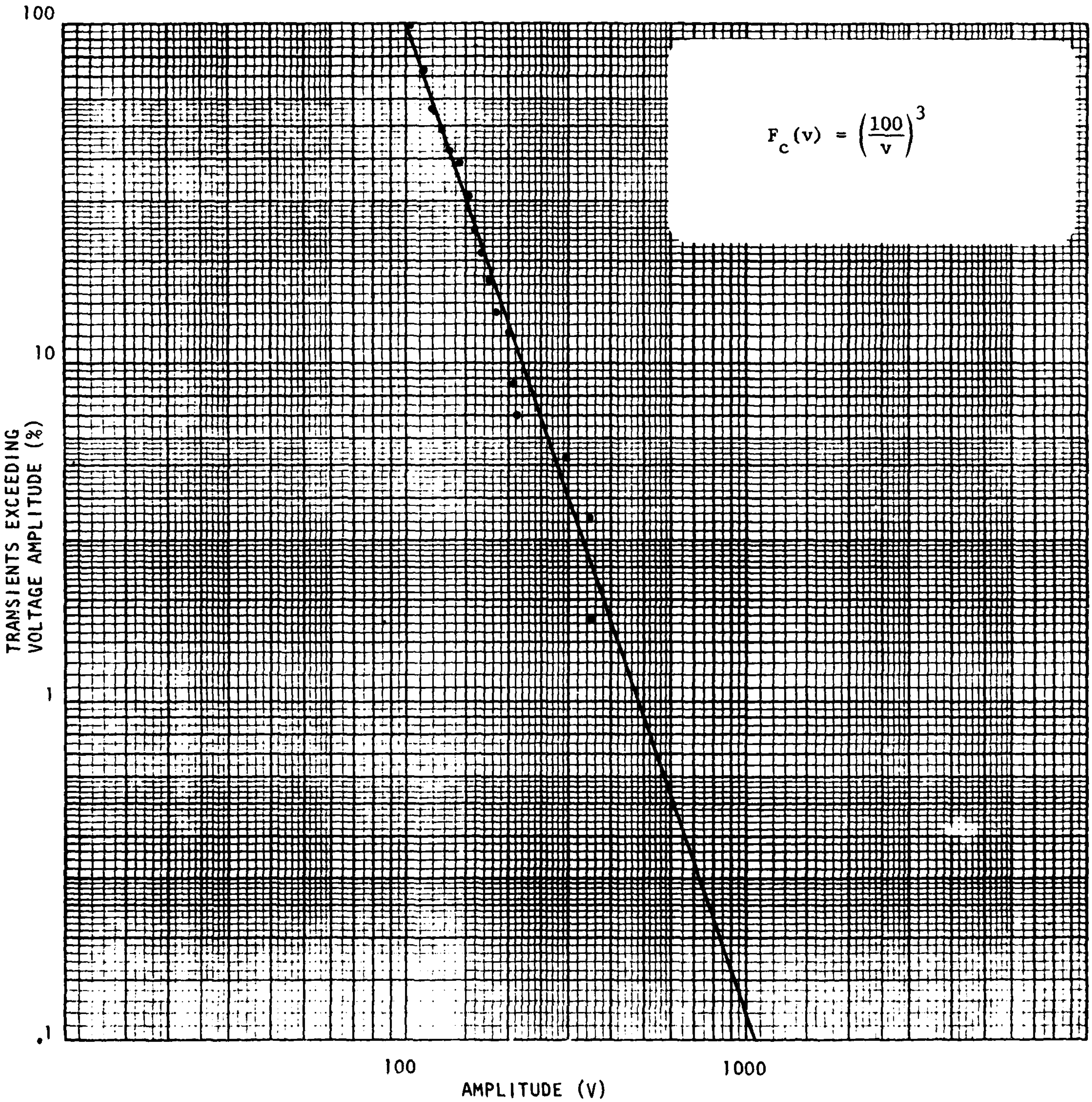


Figure A-7. Peak Amplitude Distribution
Building 225 (120V)
NAS Key West, FL

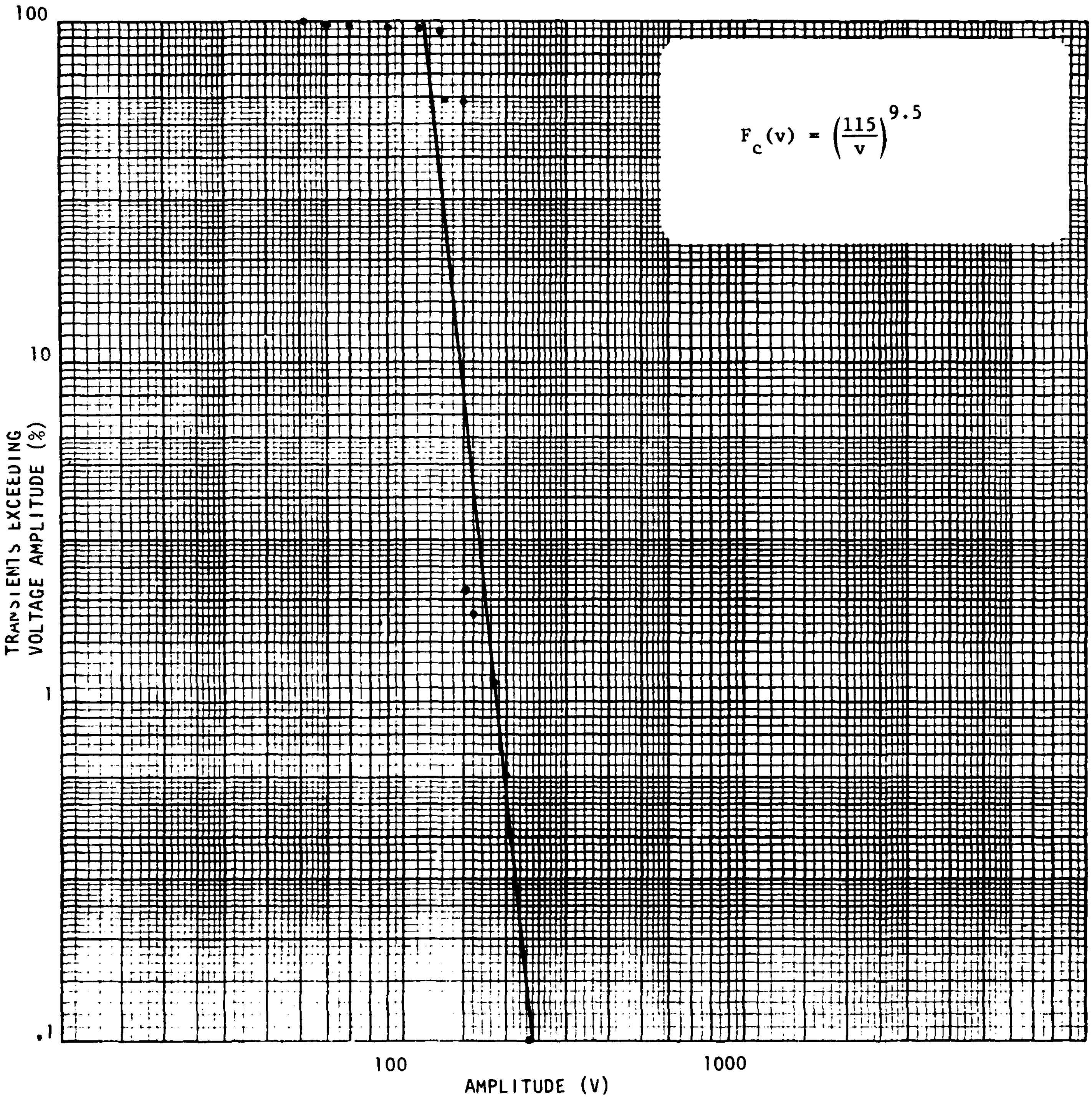


Figure A-8. Peak Amplitude Distribution
RAPCON (120V)
NAS Key West, FL

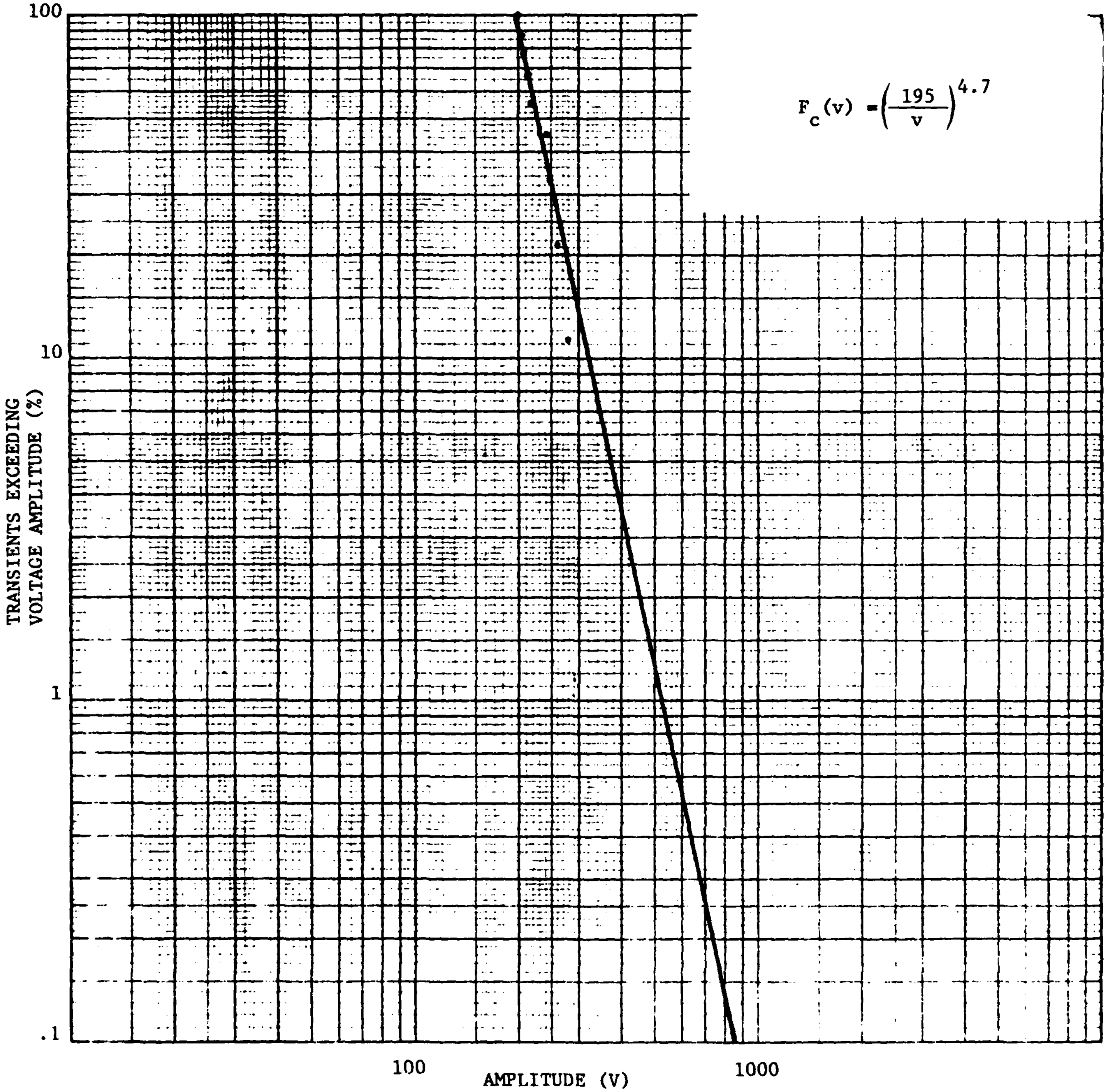


Figure A-9. Peak Amplitude Distribution
GCA Radar Site (120V)
NAS Key West, FL

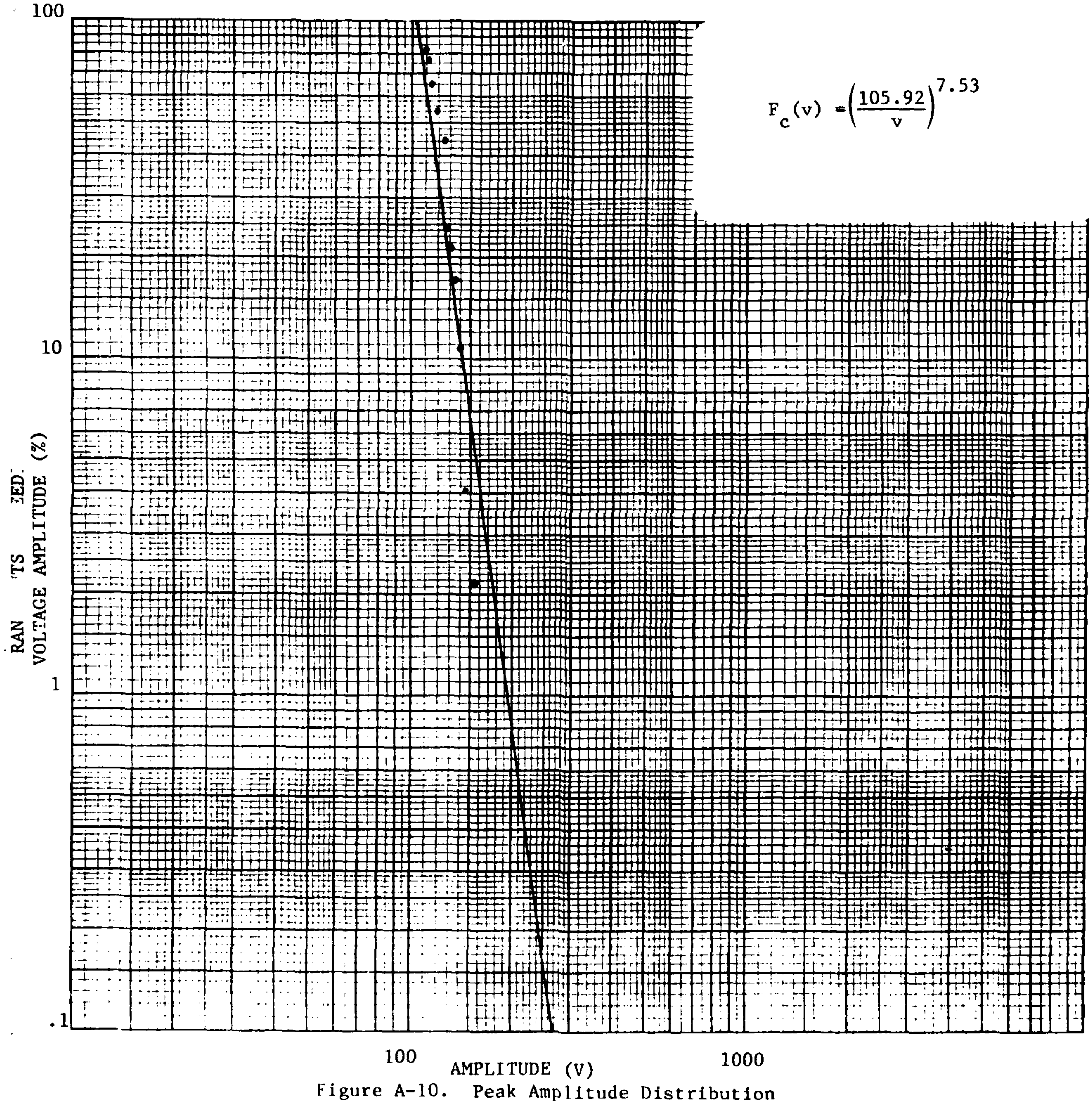


Figure A-10. Peak Amplitude Distribution
TACAN Site (120V)
NAS Key West, FL

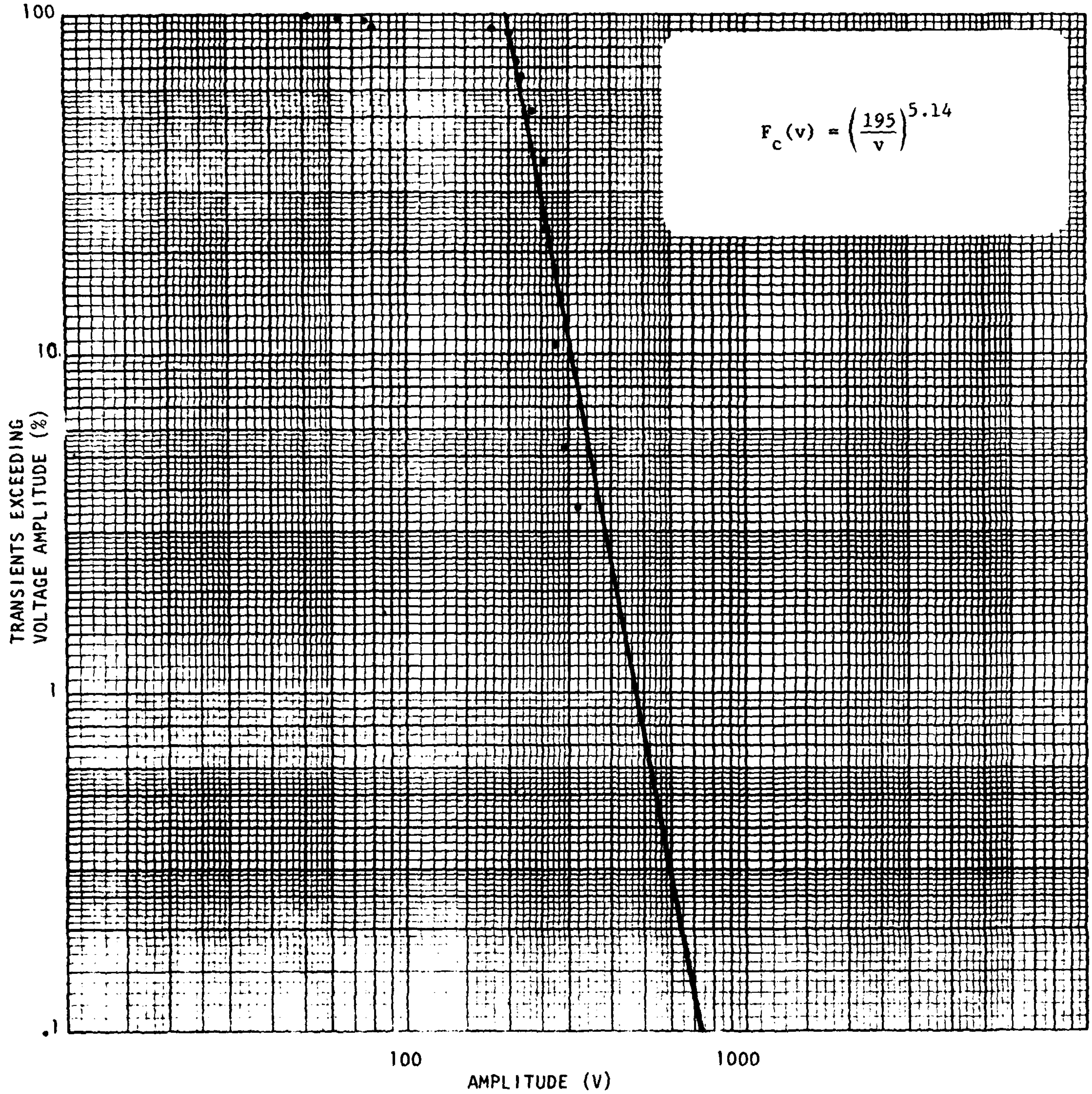


Figure A-11. Peak Amplitude Distribution
Remote Weather Station (Single Phase) (120V)
NAS Key West, FL

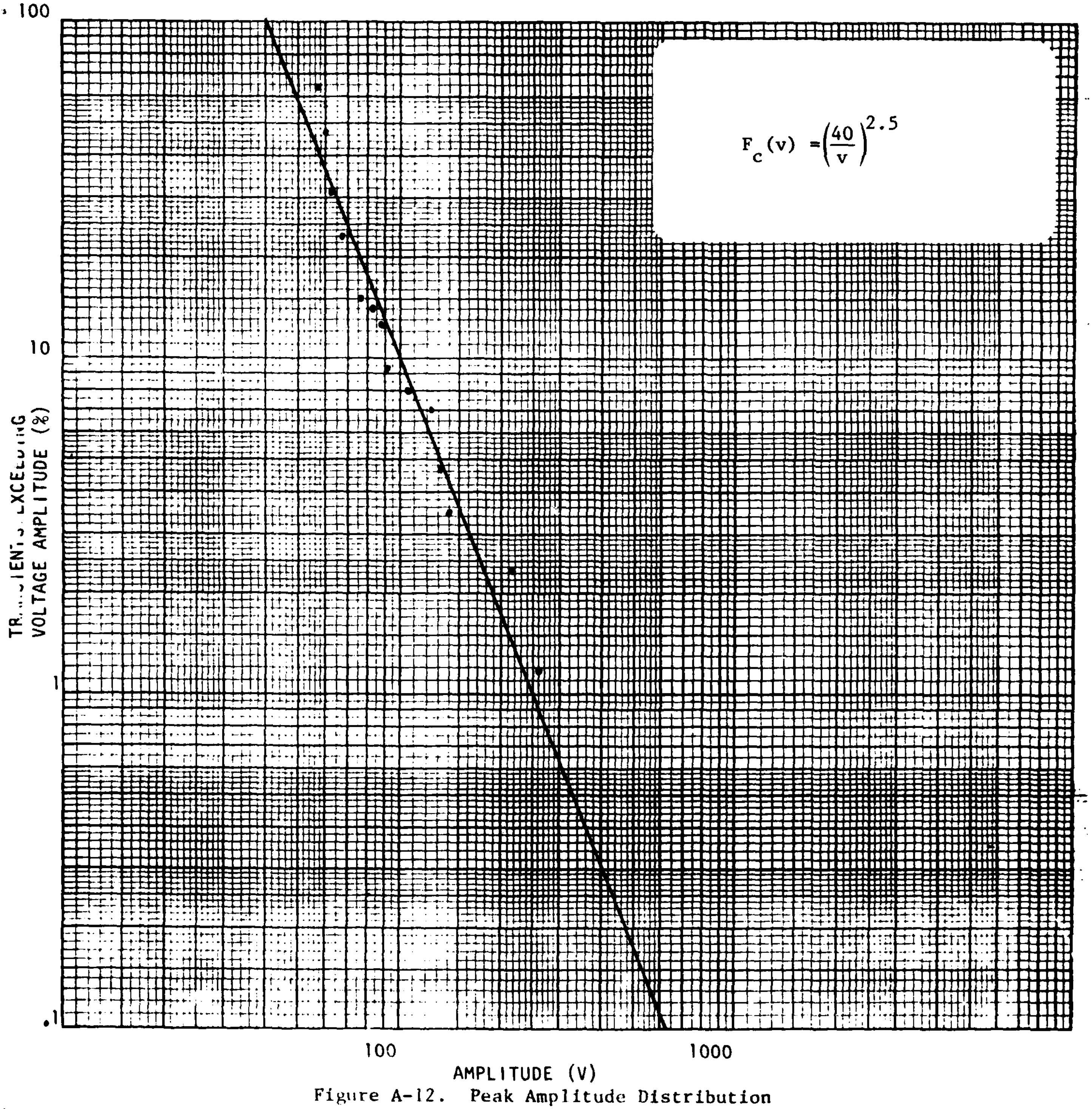


Figure A-12. Peak Amplitude Distribution
Transmitter Site (120V)
NAS Key West, FL

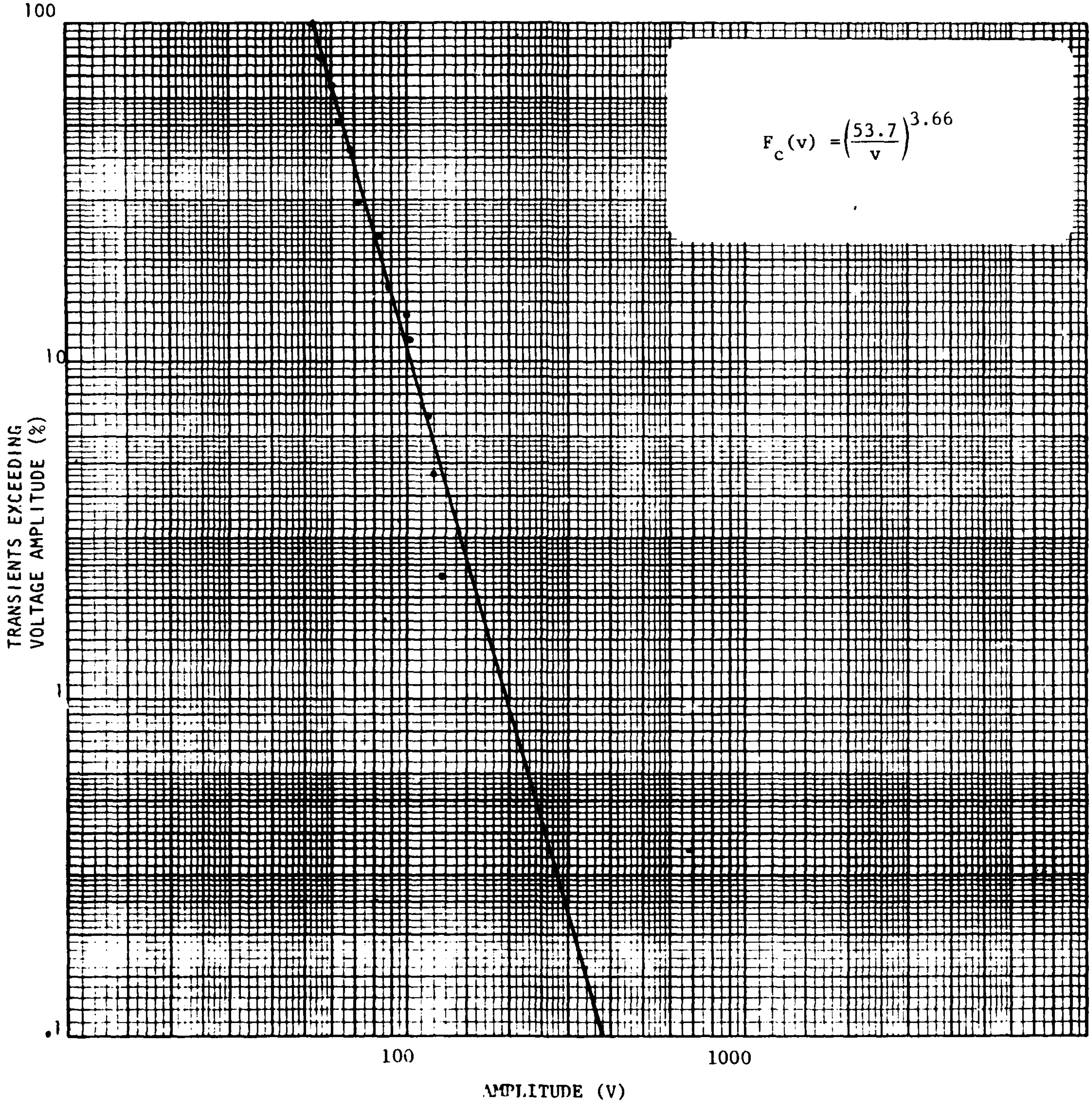


Figure A-13. Peak Amplitude Distribution
Room 309, Building 52 (120V)
U.S. Naval Observatory, Washington, DC

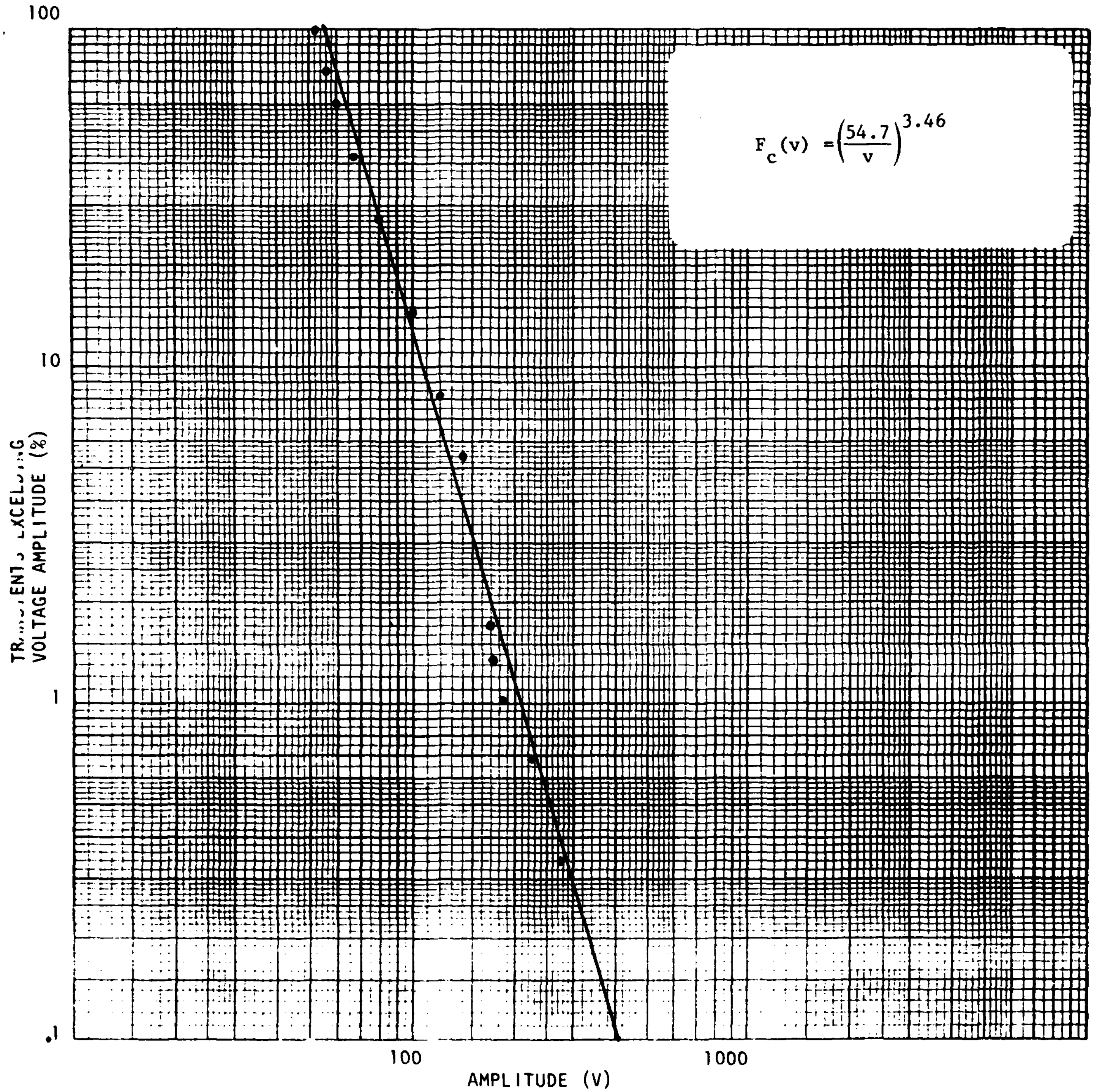


Figure A-14. Peak Amplitude Distribution
Building L-28, Room 143 (120V)
ASW Training Center, Norfolk, VA

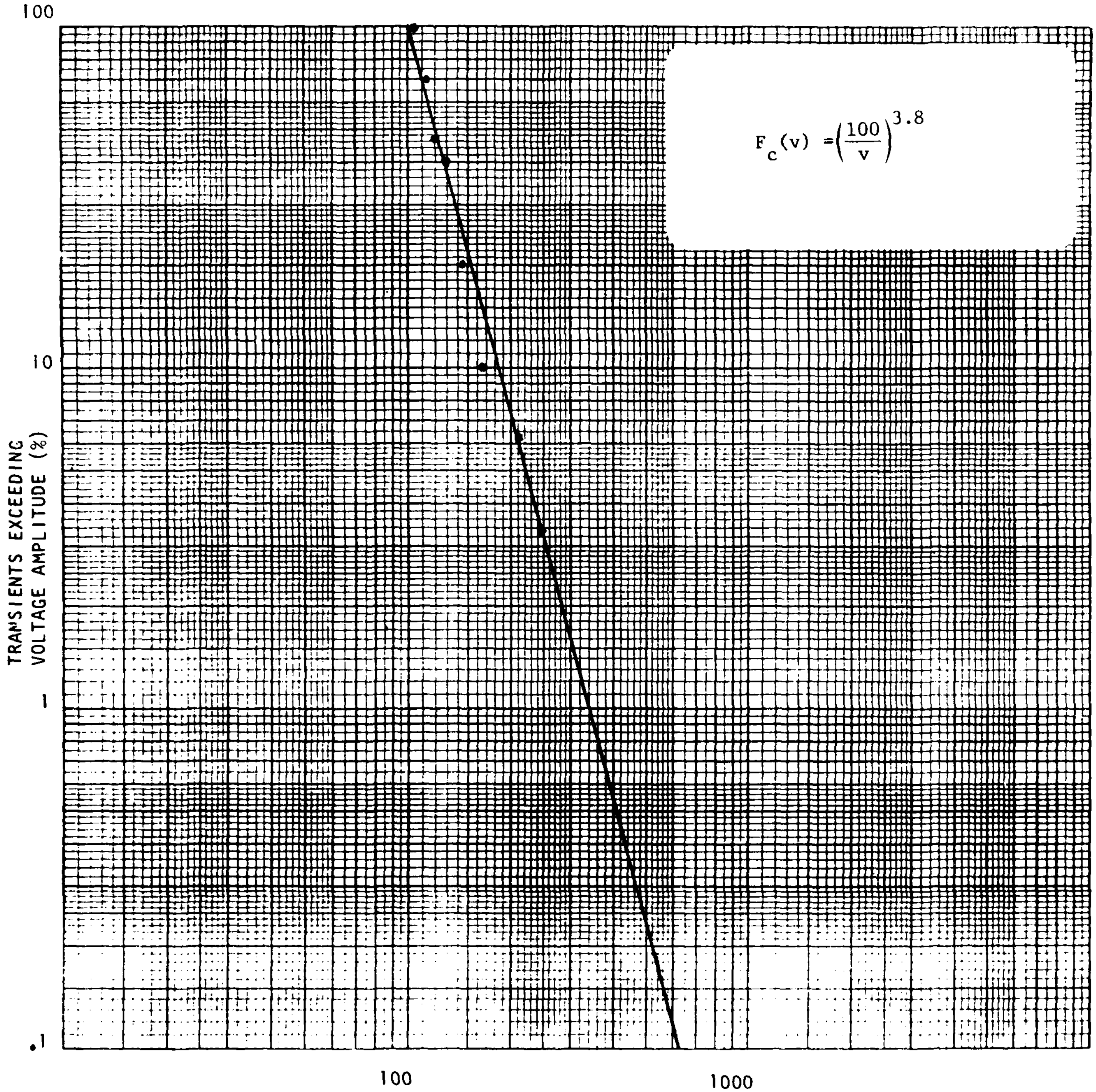


Figure A-15. Peak Amplitude Distribution
BLDG CEP-162, Room 151, Main Breaker (280V)
ASW Training Center, Norfolk, VA

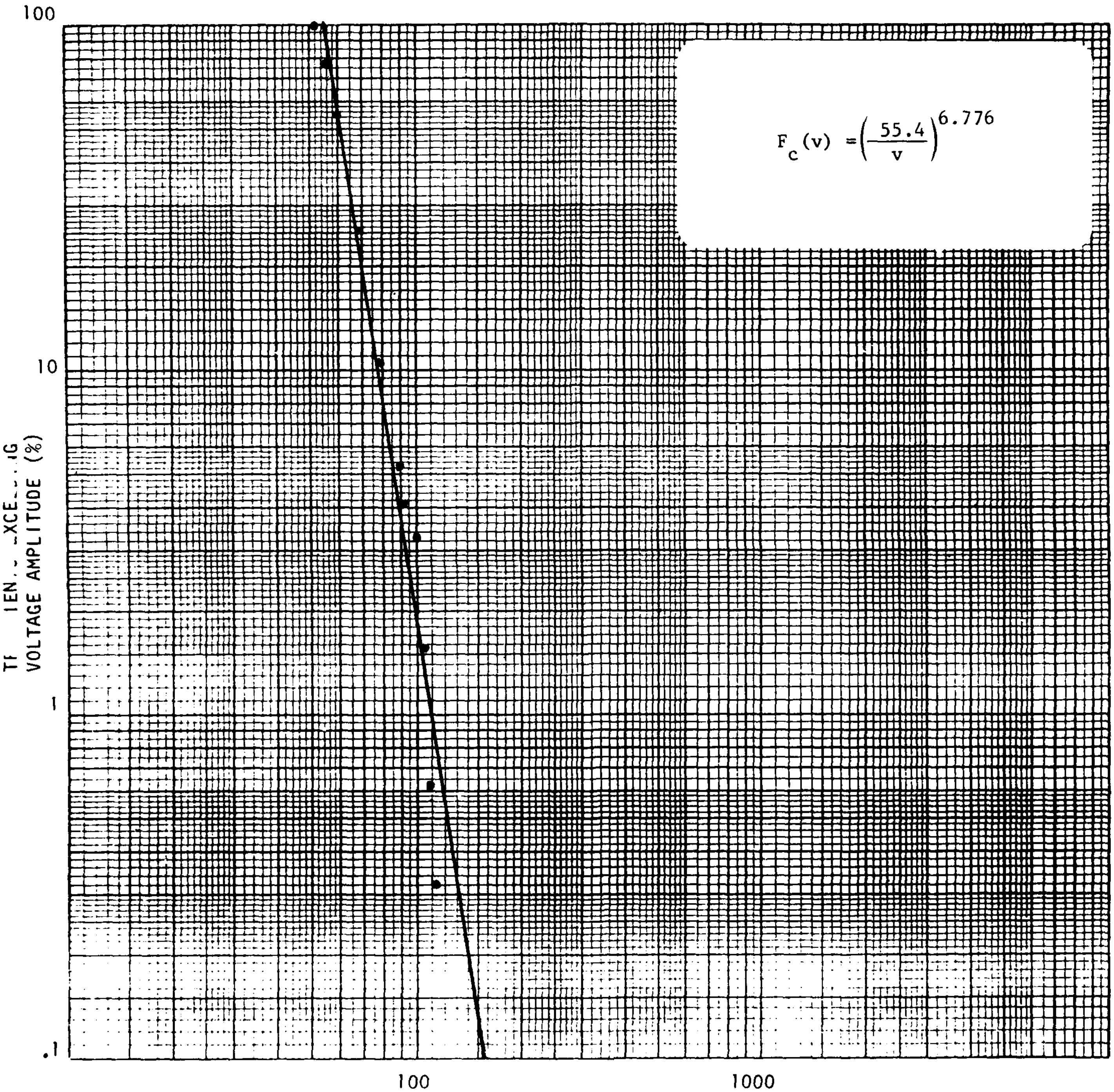


Figure A-16. Peak Amplitude Distribution
BLDG CEP-162, Room B141 (120V)
ASW Training Center, Norfolk, VA

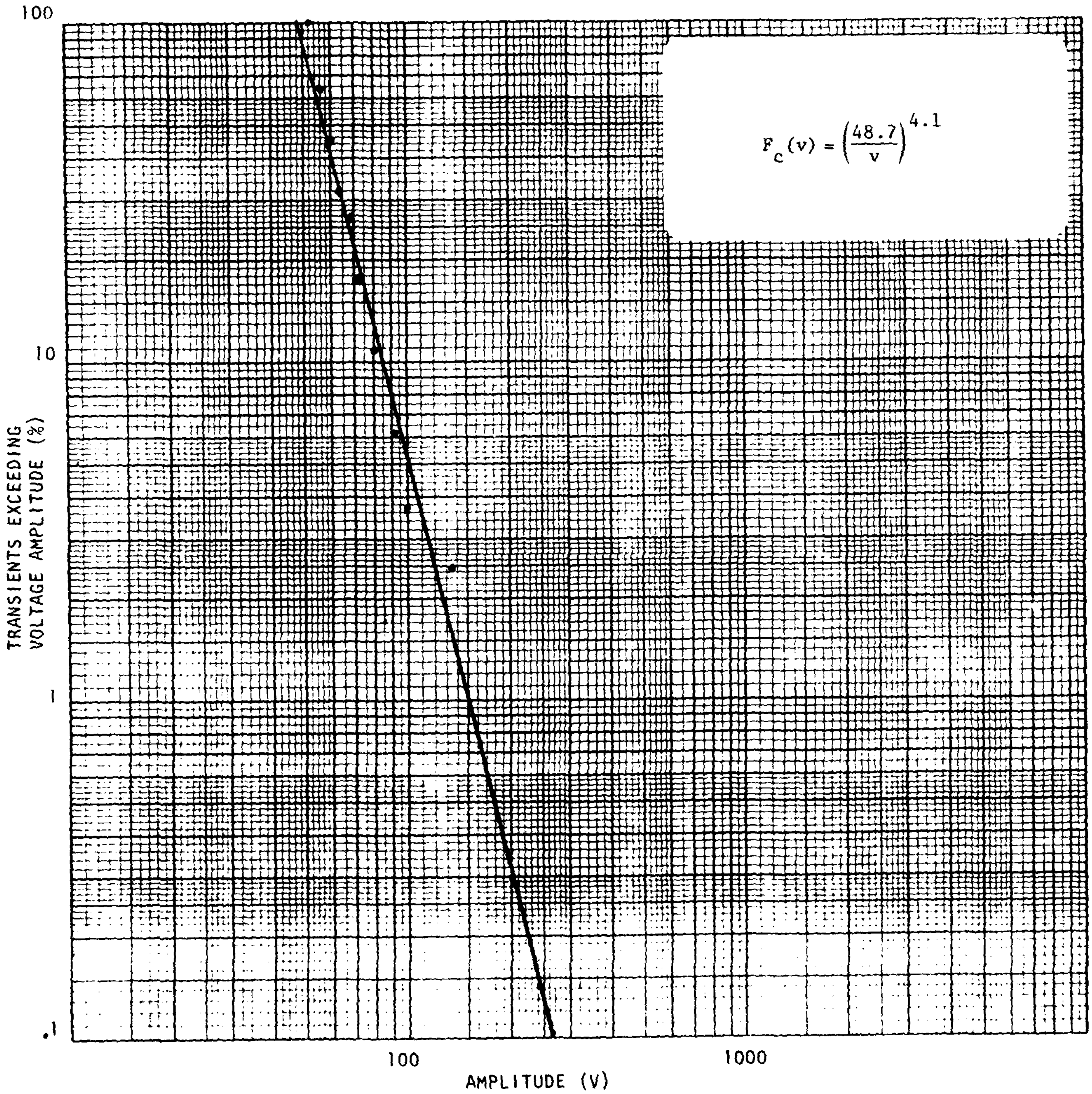


Figure A-17. Peak Amplitude Distribution
BLDG CEP-162, Room C130 (120V)
ASW Training Center, Norfolk, VA

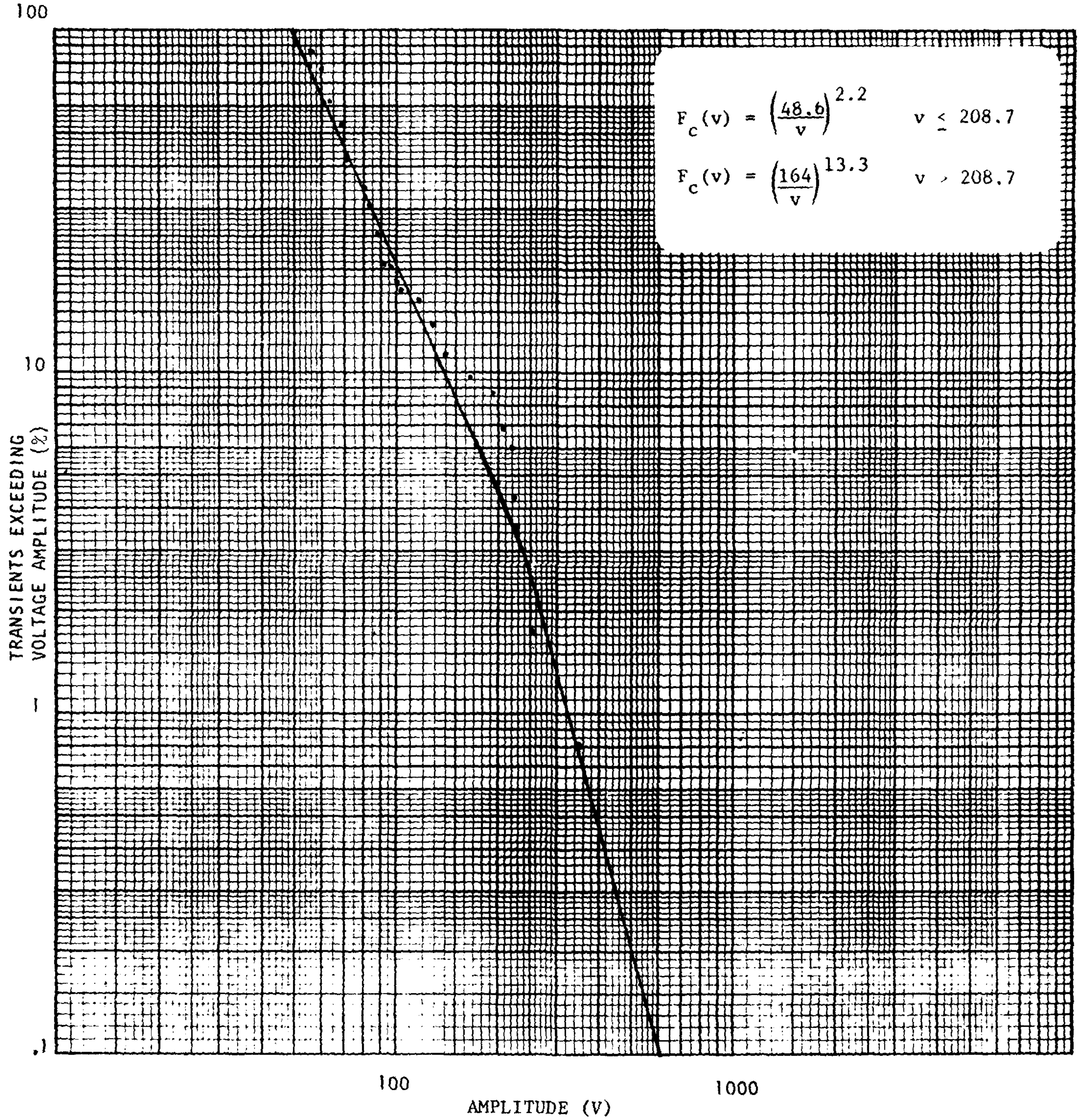


Figure A-18. Peak Amplitude Distribution
BLDG CEP-162, Room C136, Breaker T6C3 (120V)
ASW Training Center, Norfolk, VA

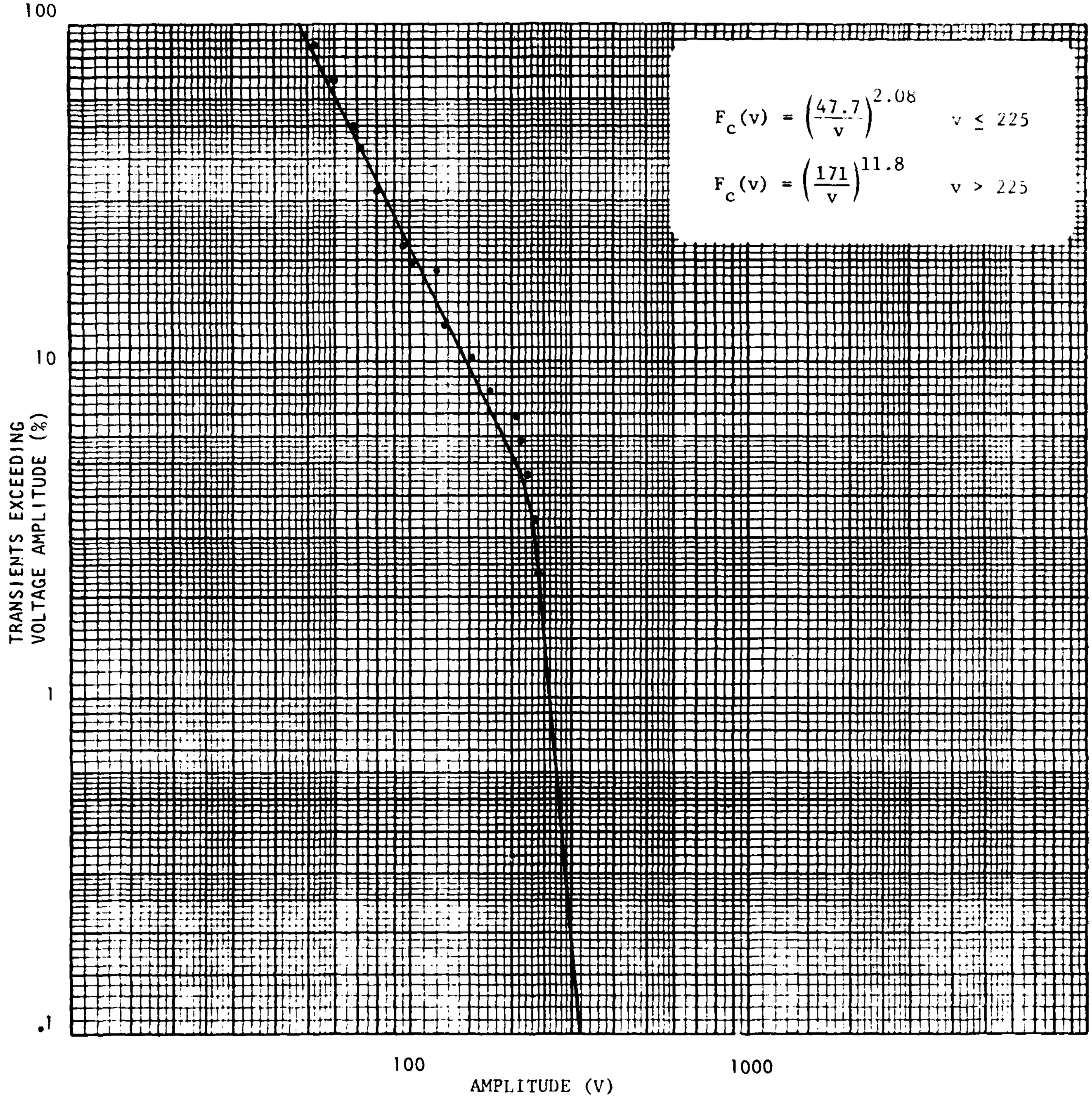


Figure A-19. Peak Amplitude Distribution
BLDG CEP-162, Room C136, Breaker T6C6 (120V)
ASW Training Center, Norfolk, VA

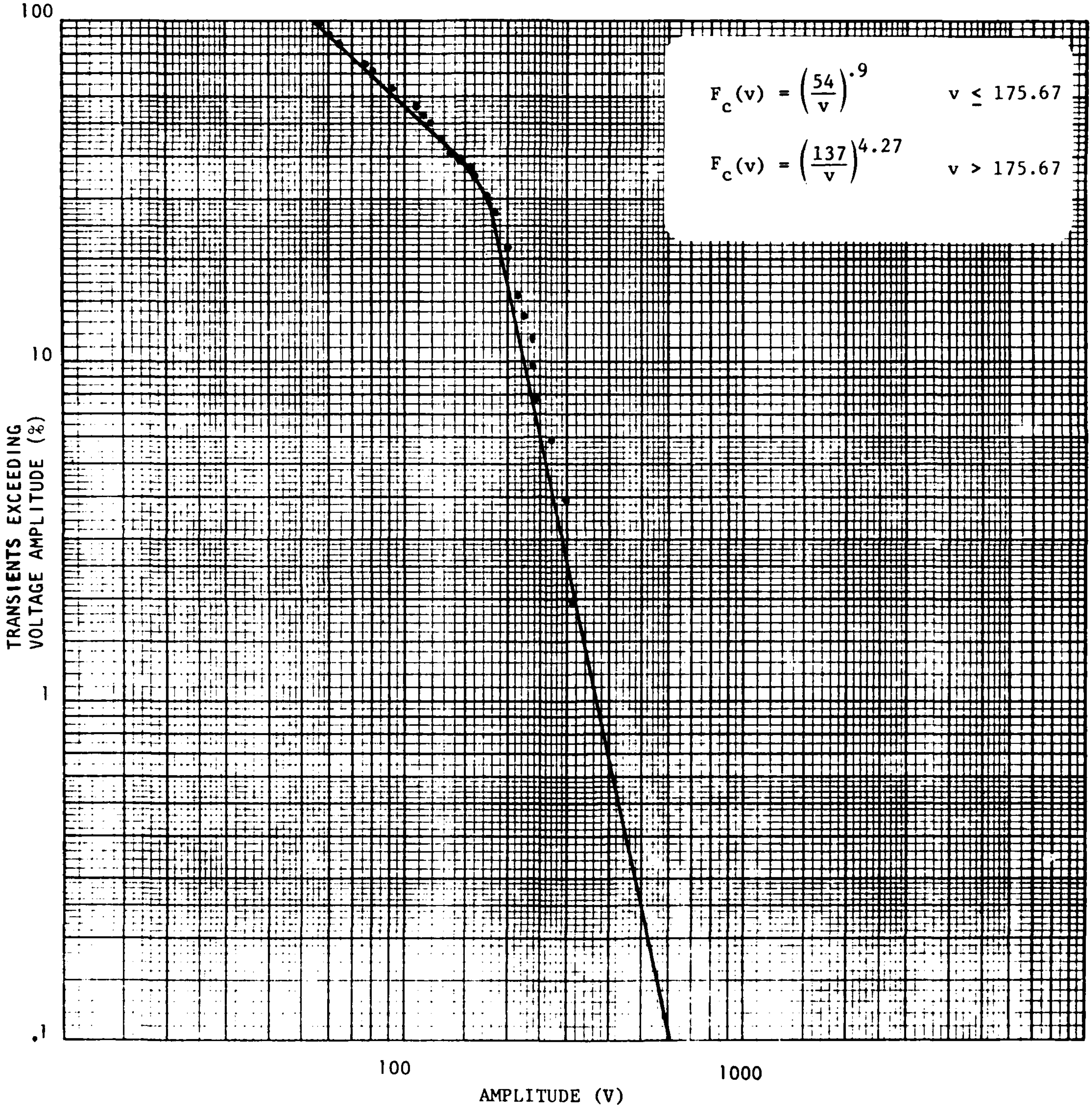


Figure A-20. Peak Amplitude Distribution
BLDG CEP-162, Room D201 (120V)
ASW Training Center, Norfolk, VA

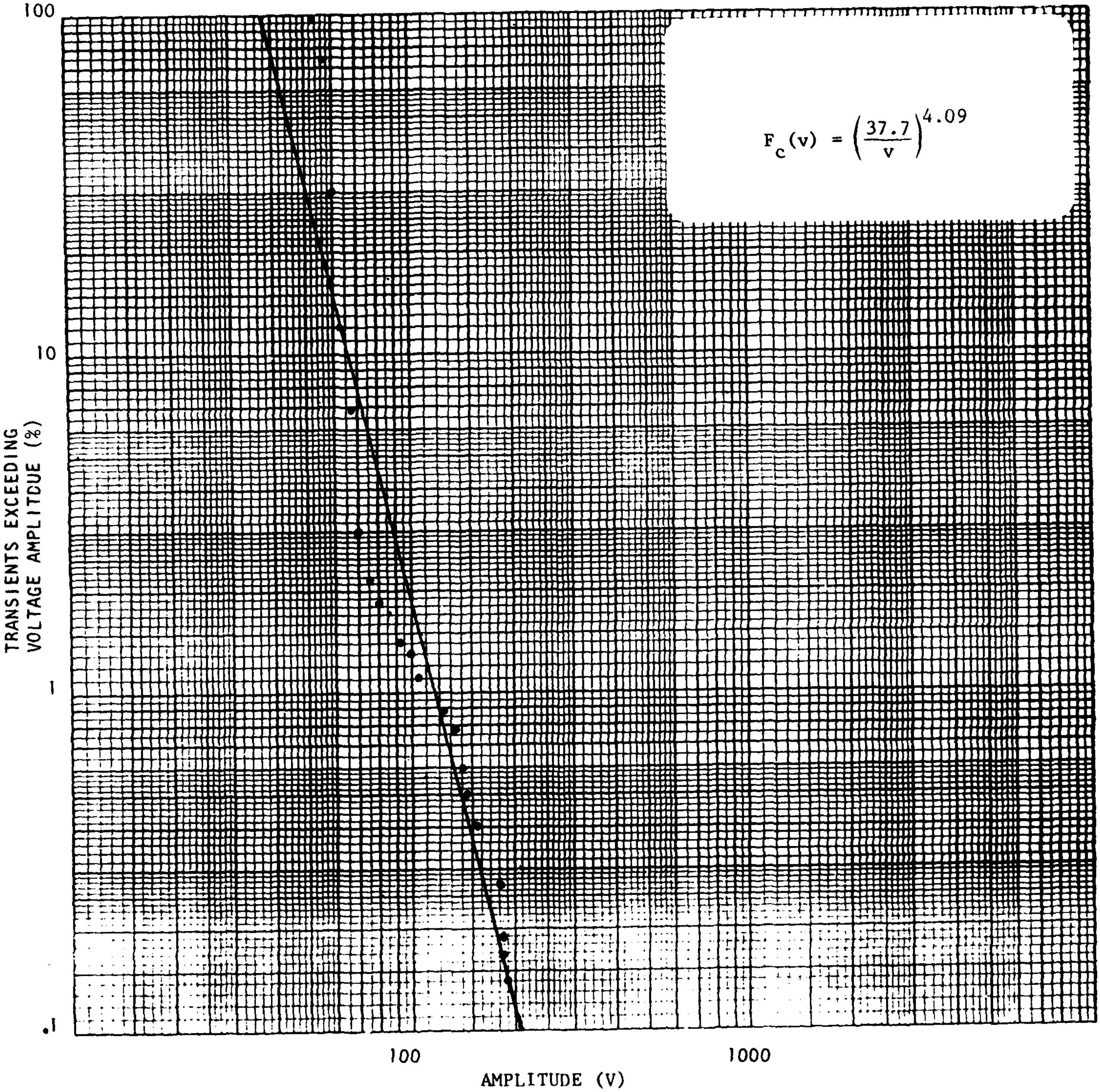


Figure A-21. **Peak Amplitude** Distribution
Generator Room, Main Power Panel (120V)
Radar Site, San Juan, PR

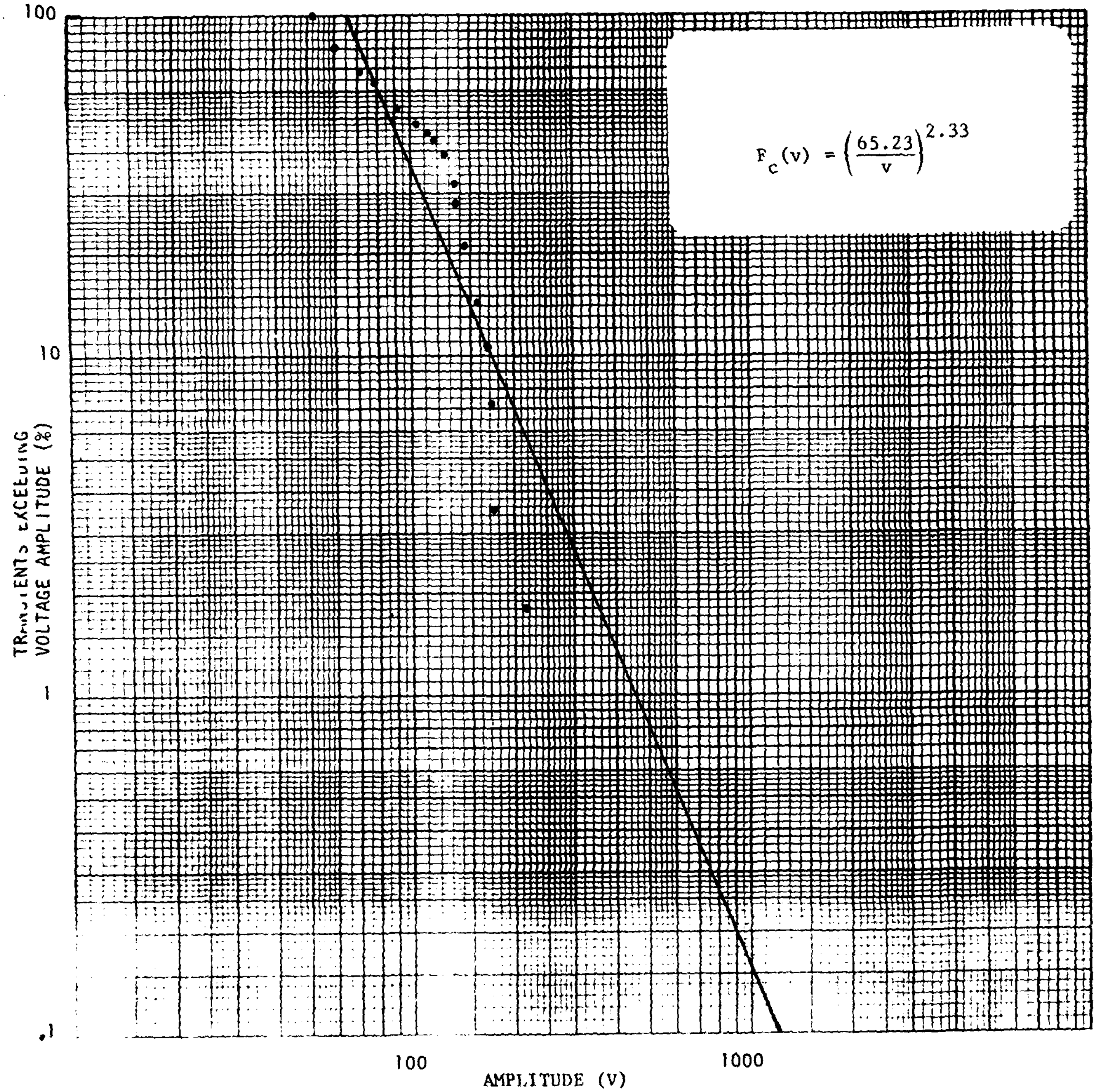


Figure A-22. Peak Amplitude Distribution
Room A, Main Power Panel (120V)
Radar Site, San Juan, PR

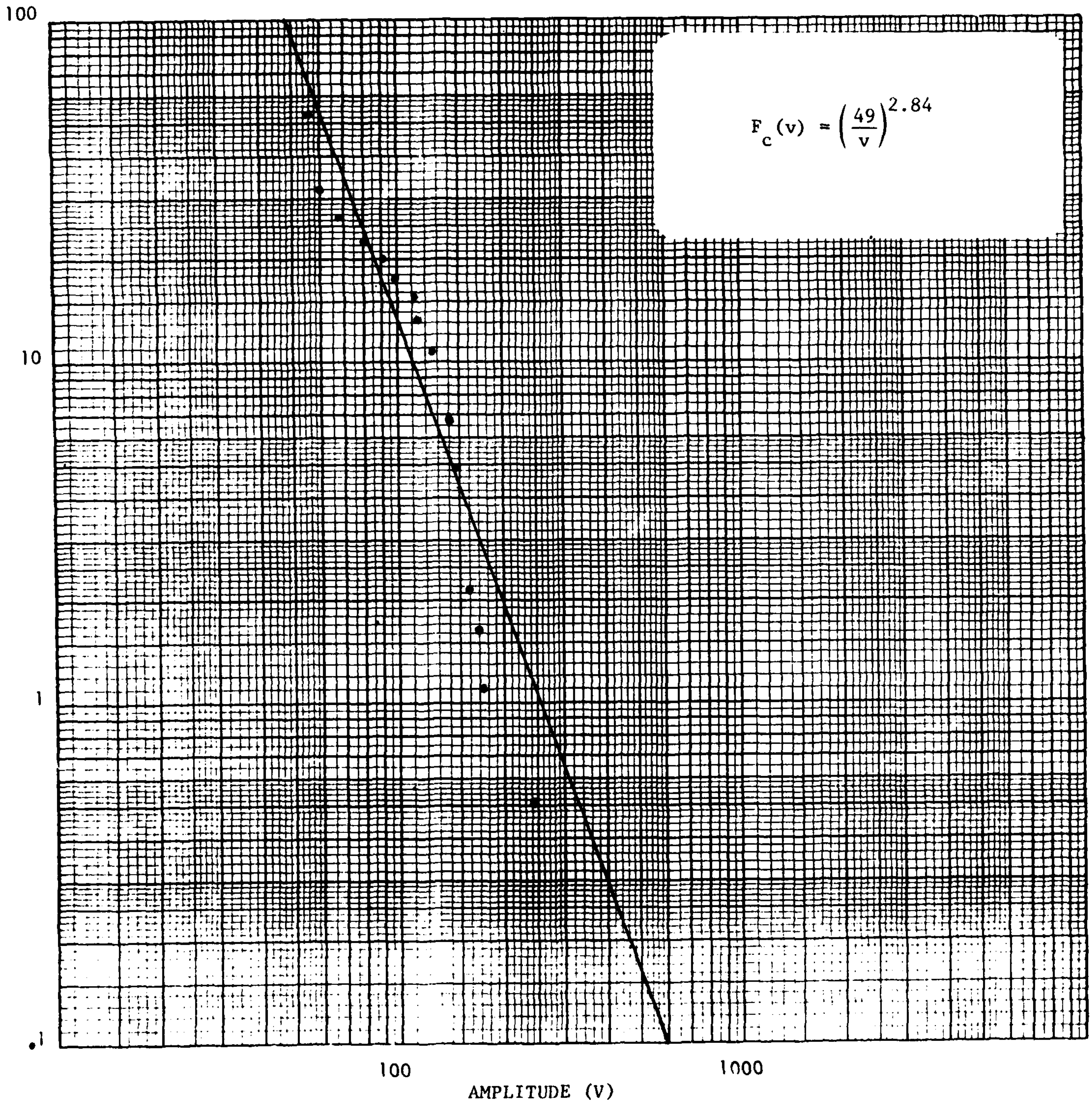


Figure A-23. Peak Amplitude Distribution
Antenna Power Panel (120V)
Radar Site, San Juan, PR

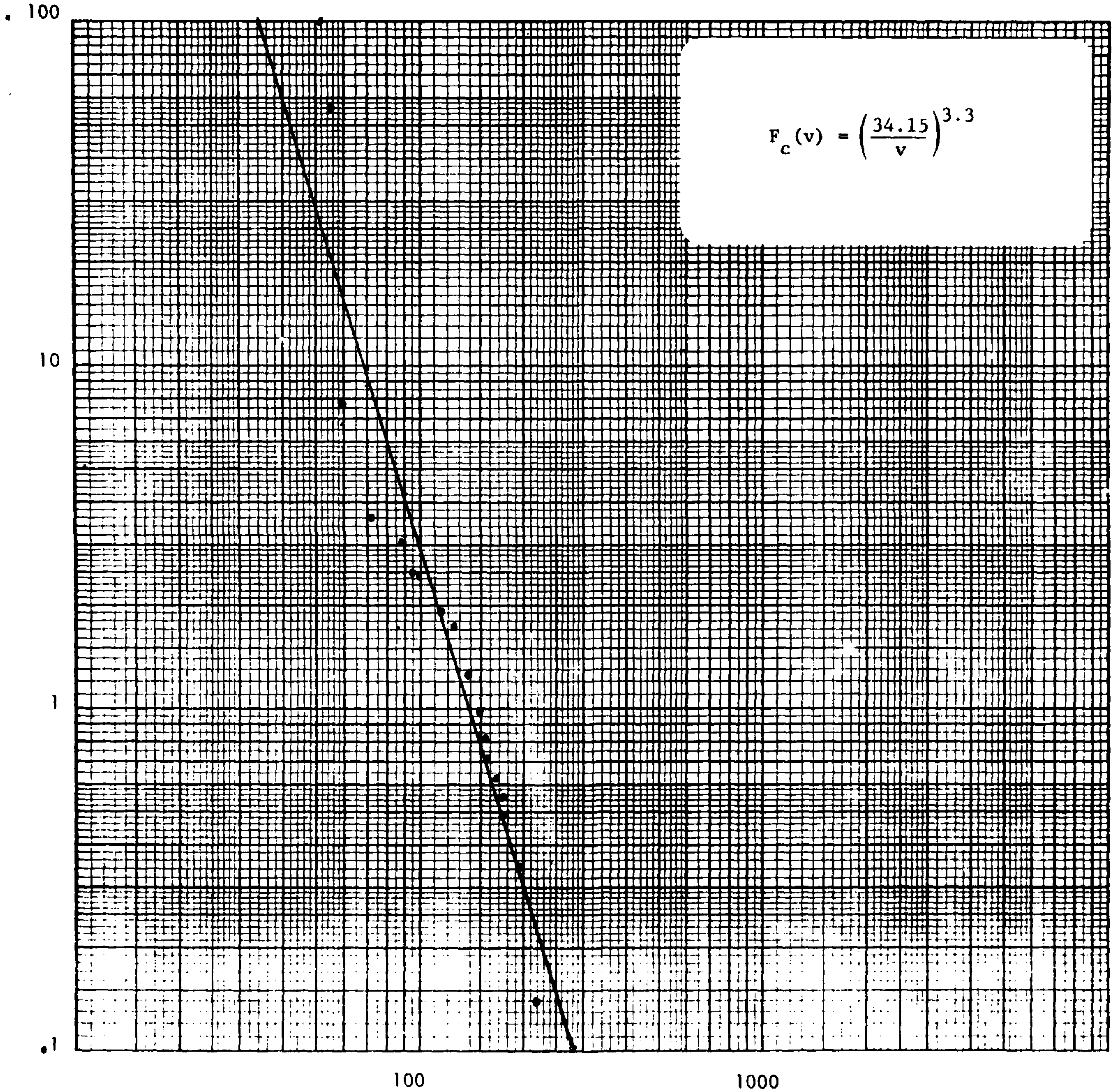


Figure A-24. Peak Amplitude Distribution
Electronics Room B, Power Panel A14 (120V)
Radar Site, San Juan, PR

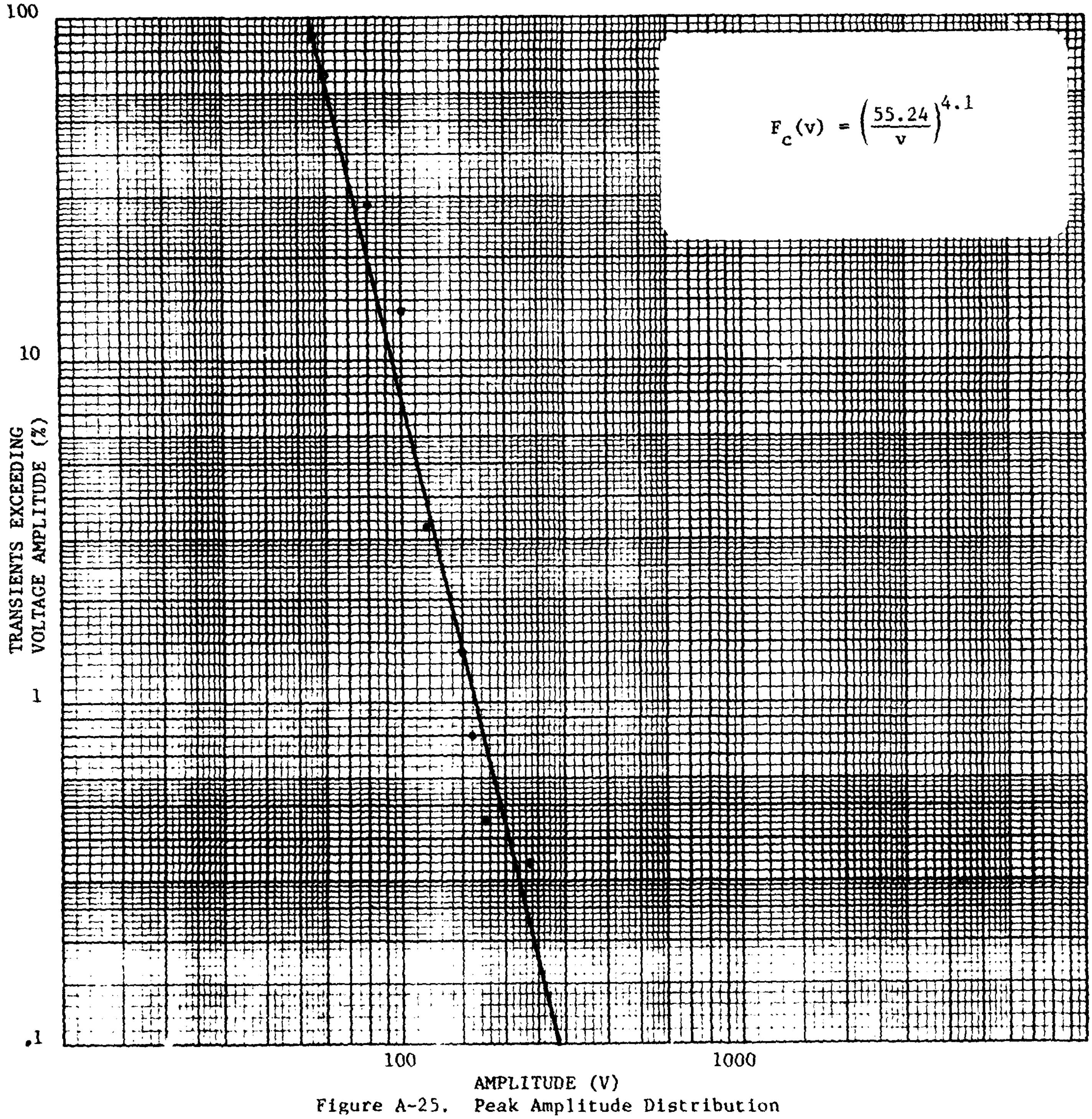


Figure A-25. Peak Amplitude Distribution
Room 02A, Panel 5A03, Sonar Team Trainer (120V)
Fleet Training Center, BLDG 127, Dam Neck, VA

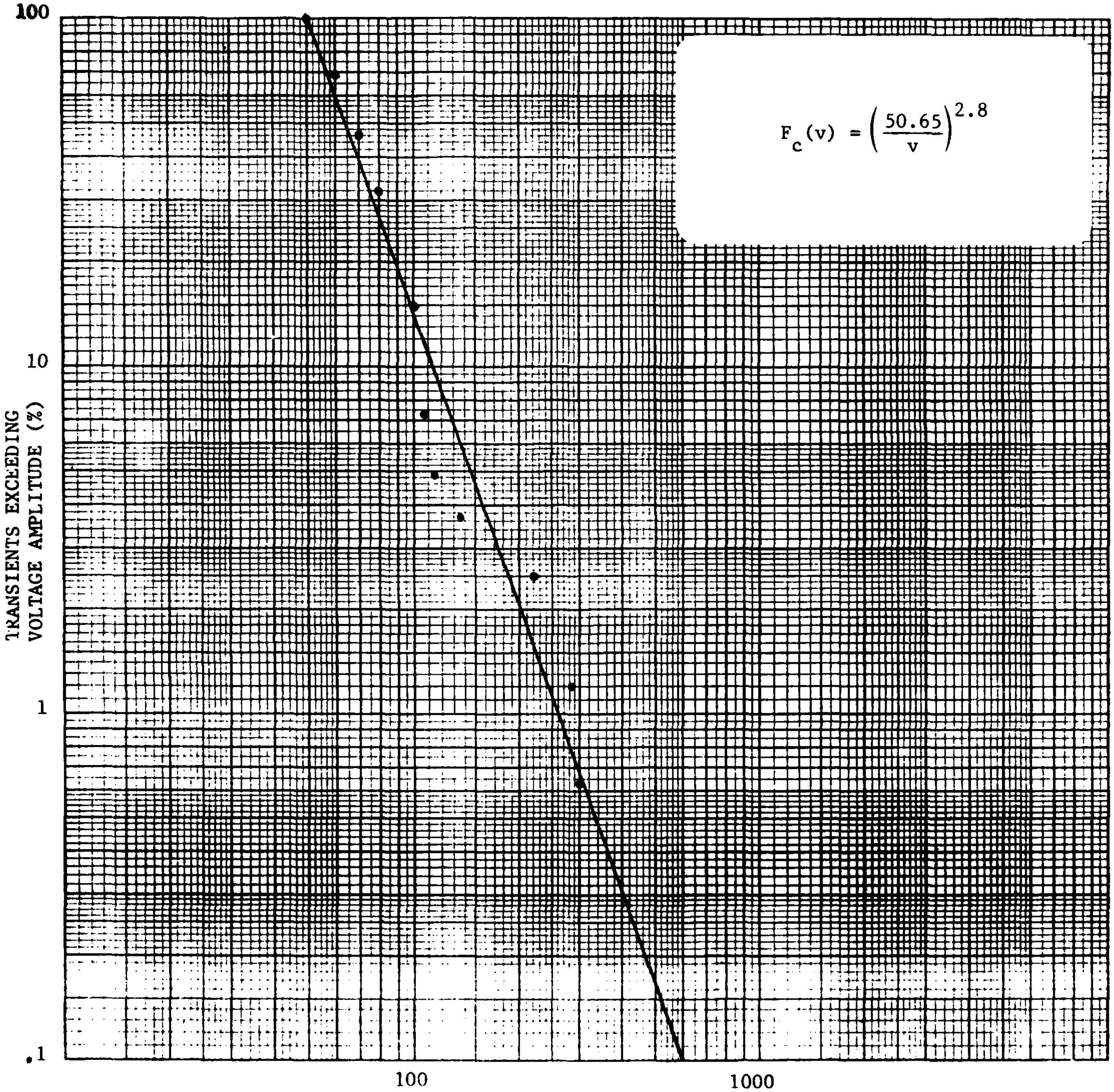


Figure 26. Peak Amplitude Distribution
Room 40, RADNAV Trainer (120V)
Fleet Training Center, BLDG 127, Dam Neck, VA

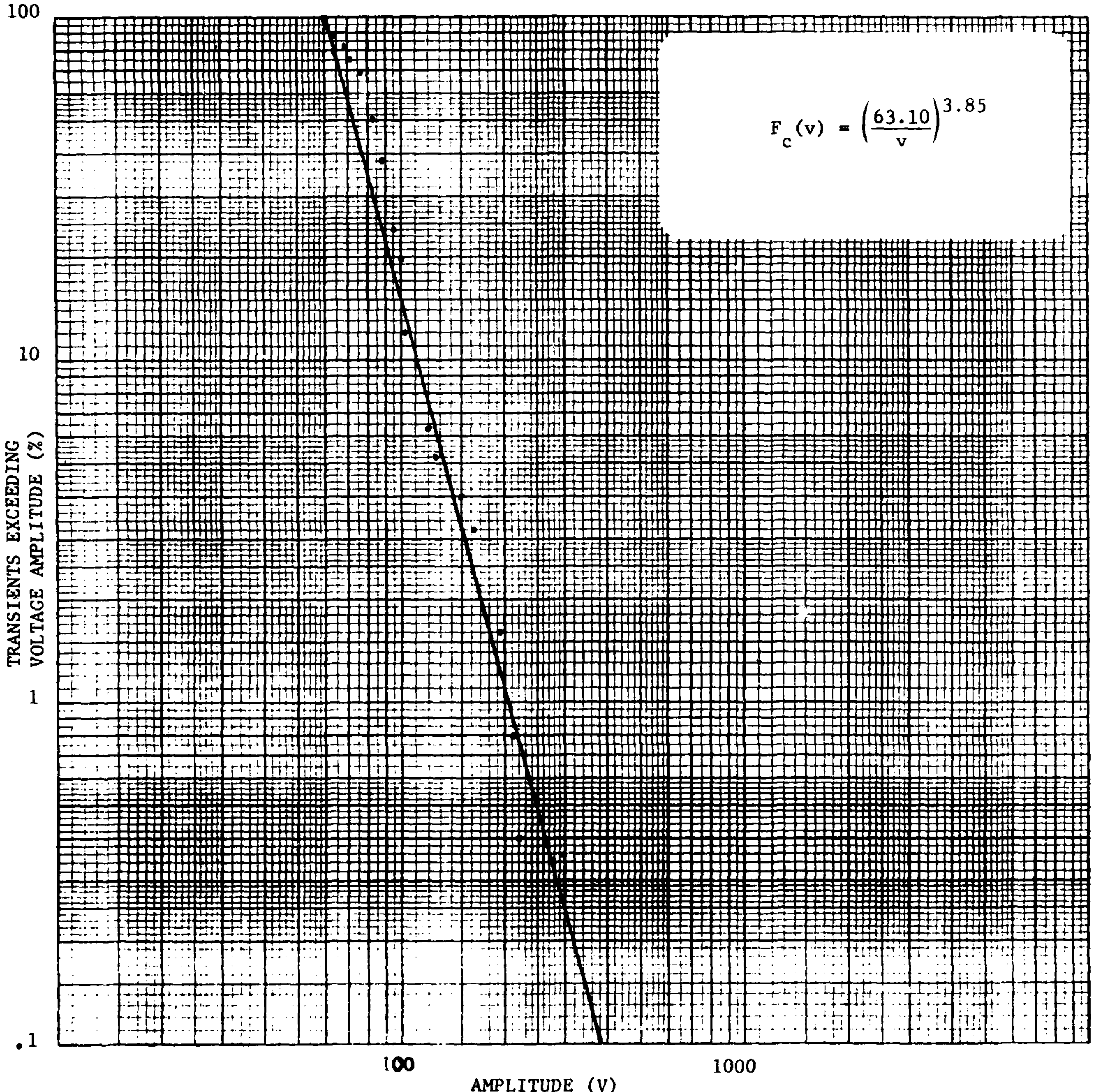


Figure A-27. Peak Amplitude Distribution
Room 43, Panel 43-3, FFG-7 (120V)
Fleet Training Center, BLDG 127, Dam Neck, VA

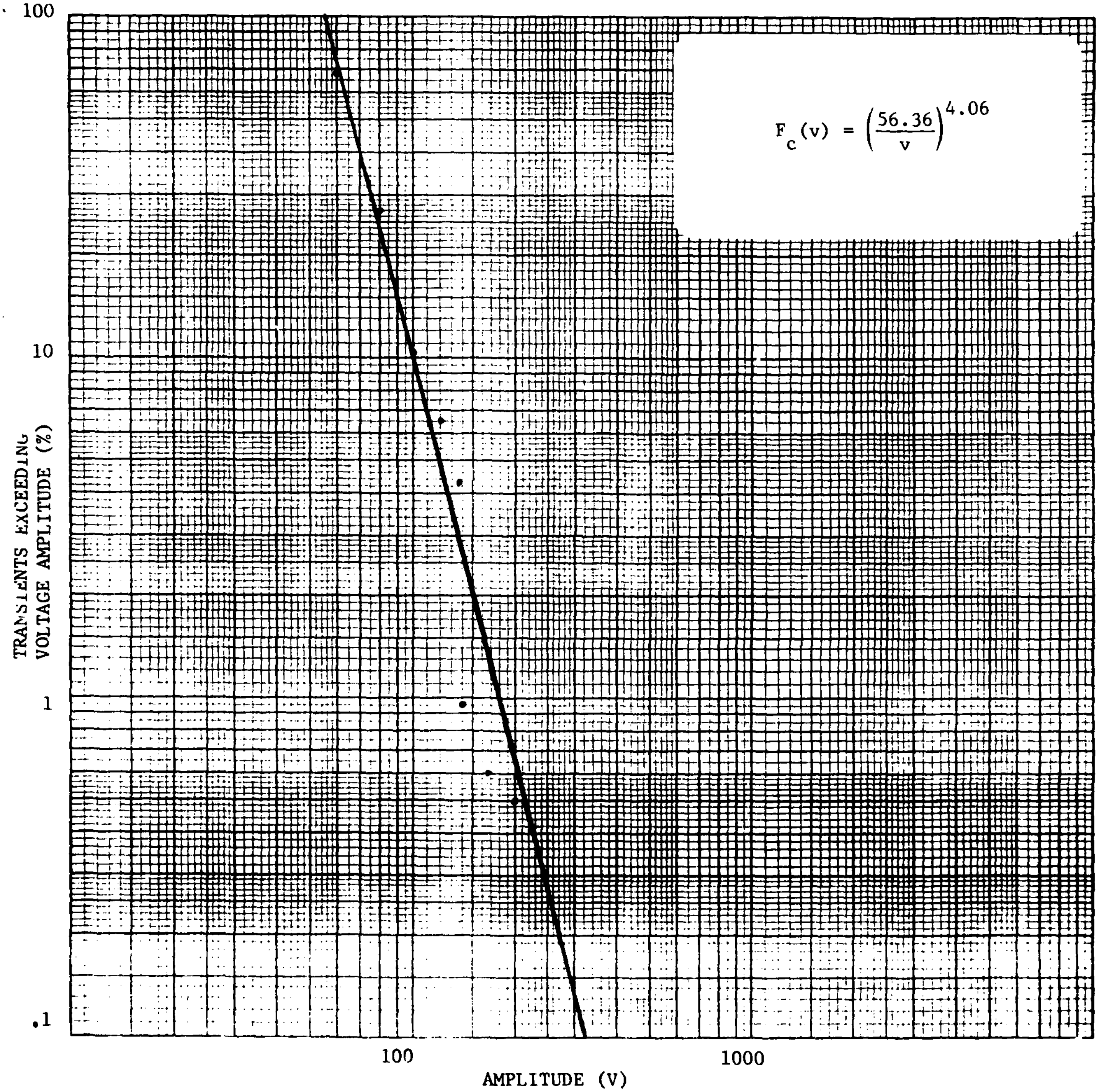


Figure A-28. Peak Amplitude Distribution
Room 114, Panel EP-2, Computer Complex (120V)
Fleet Training Center, BLDG 127, Dam Neck, VA

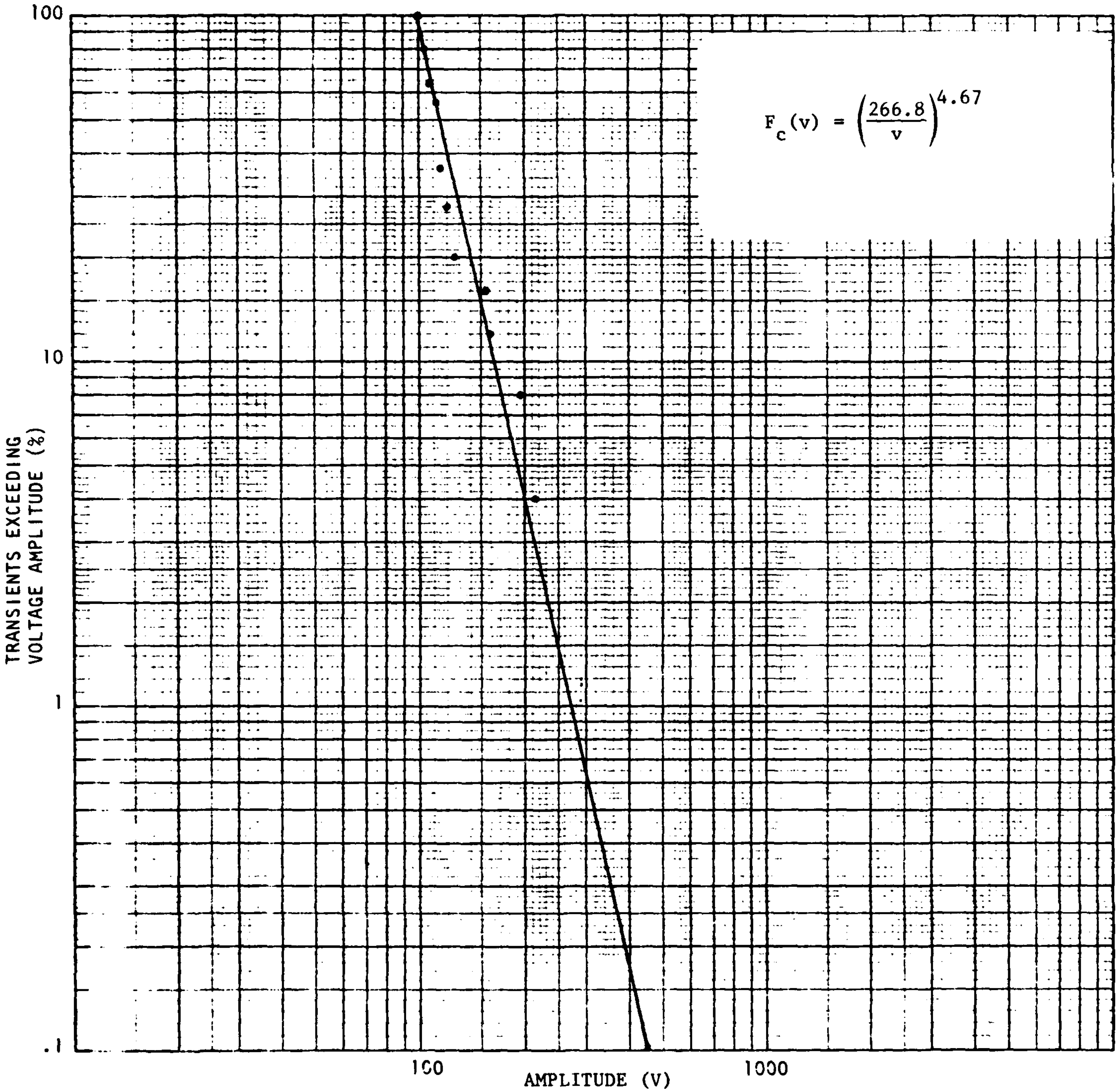


Figure A-29. Peak Amplitude Distribution
Room 43, Sensor Simulation Subsystem (120V)
Fleet Training Center, Bldg. 127
Dam Neck, VA

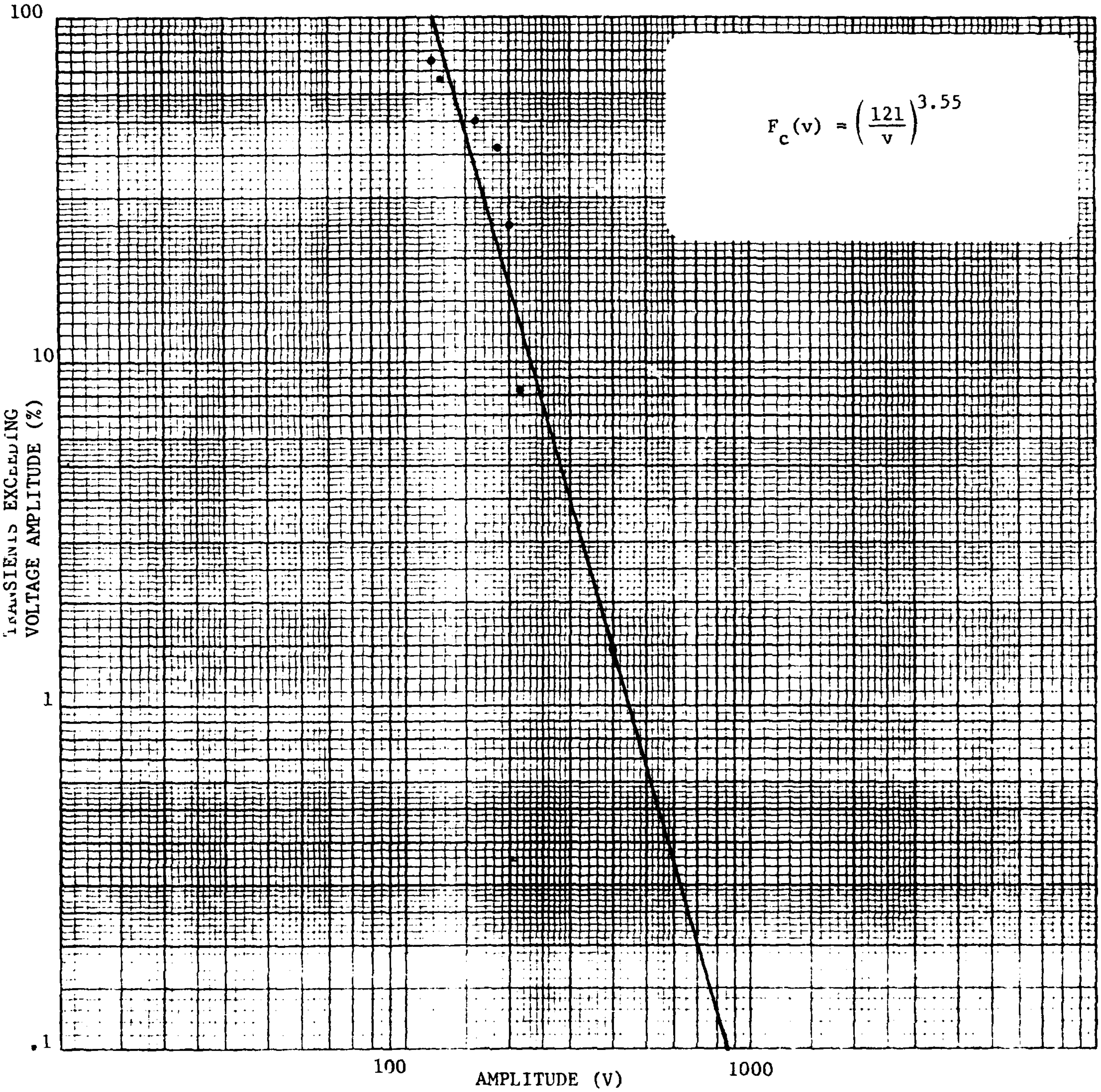


Figure A-30. Peak Amplitude Distribution
Main BLDG Power Input Panel (120V)
Navy Amphibious Base, Little Creek, VA

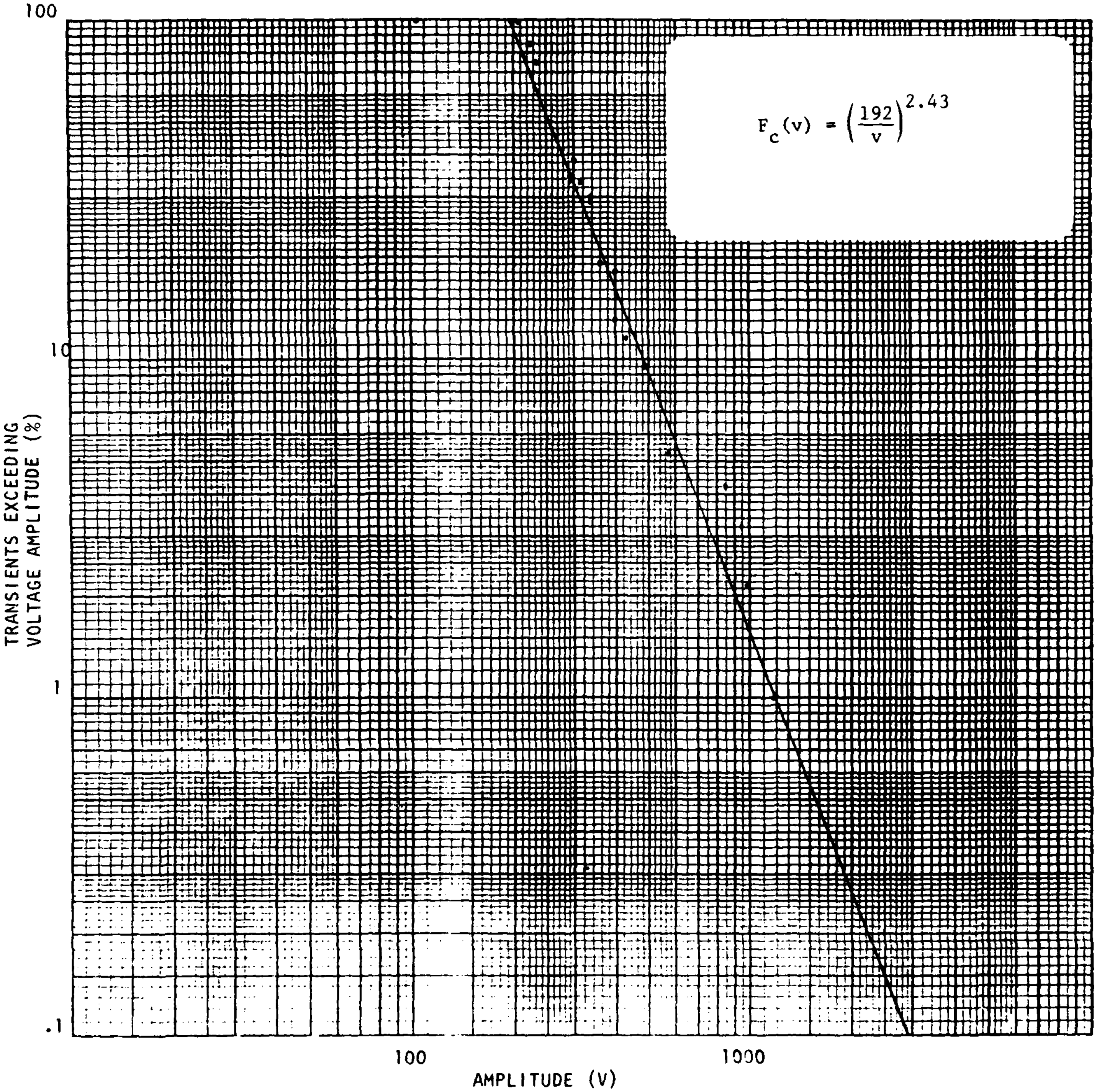


Figure A-31. Peak Amplitude Distribution
2-F114 Trainer Transformer, Line to Line (480V)
NAS Oceana, VA

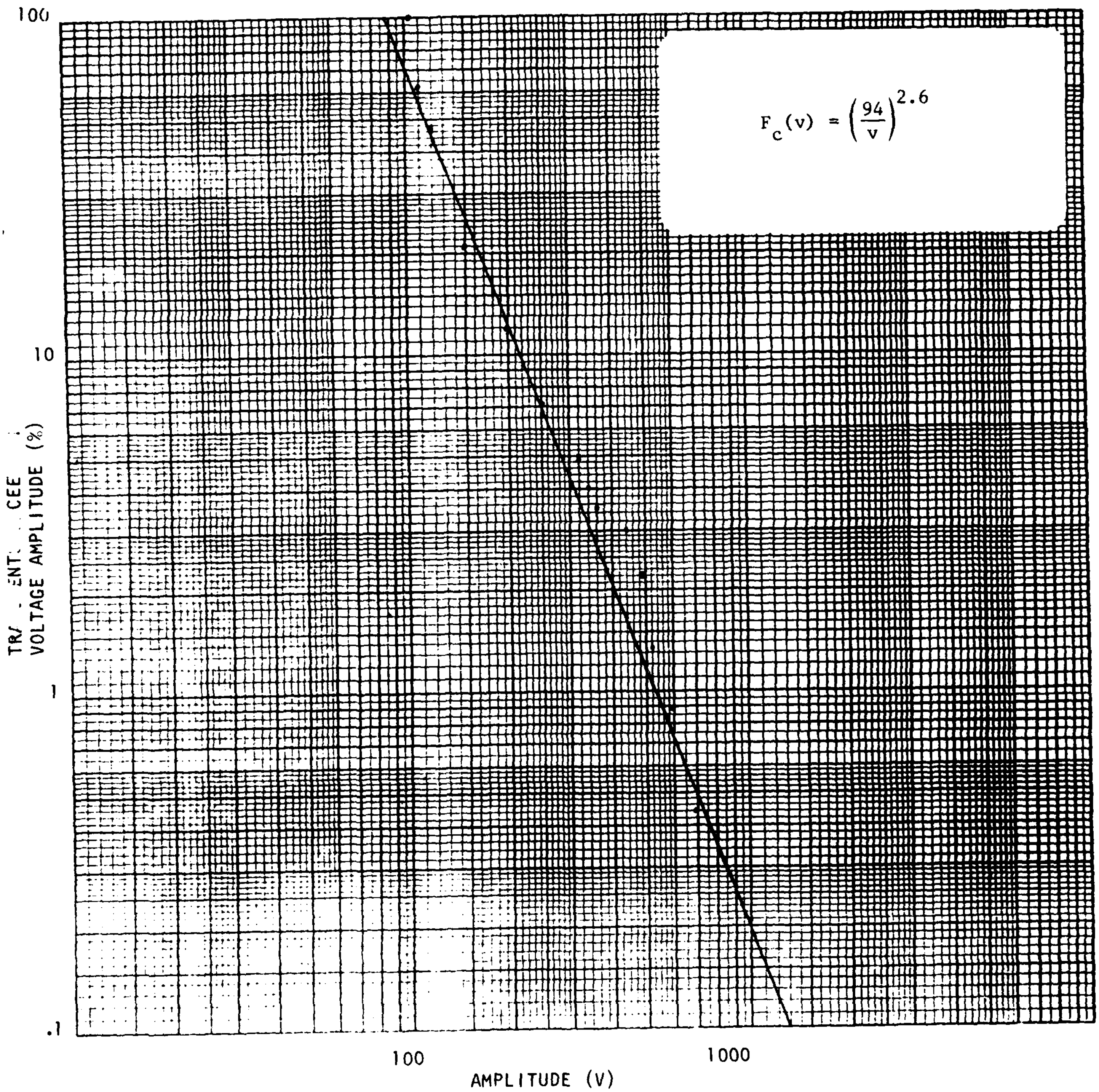


Figure A-32. Peak Amplitude Distribution
2-F114 Trainer Transformer, Line to Ground (480V)
NAS Oceana, VA

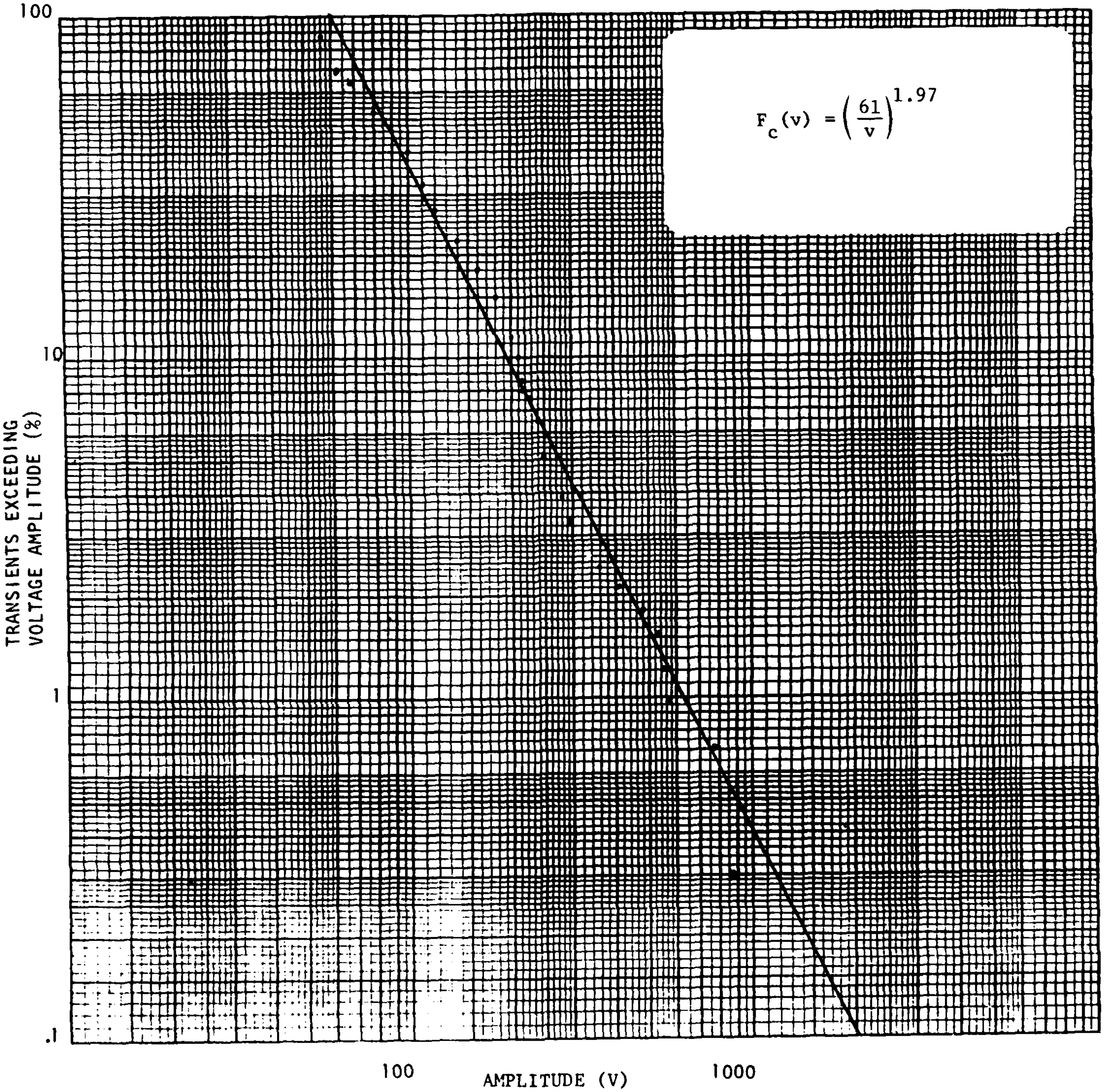


Figure A-33. Peak Amplitude Distribution
2-F114 Trainer Transformer, Main Power Panel (120V)
NAS Oceana, VA

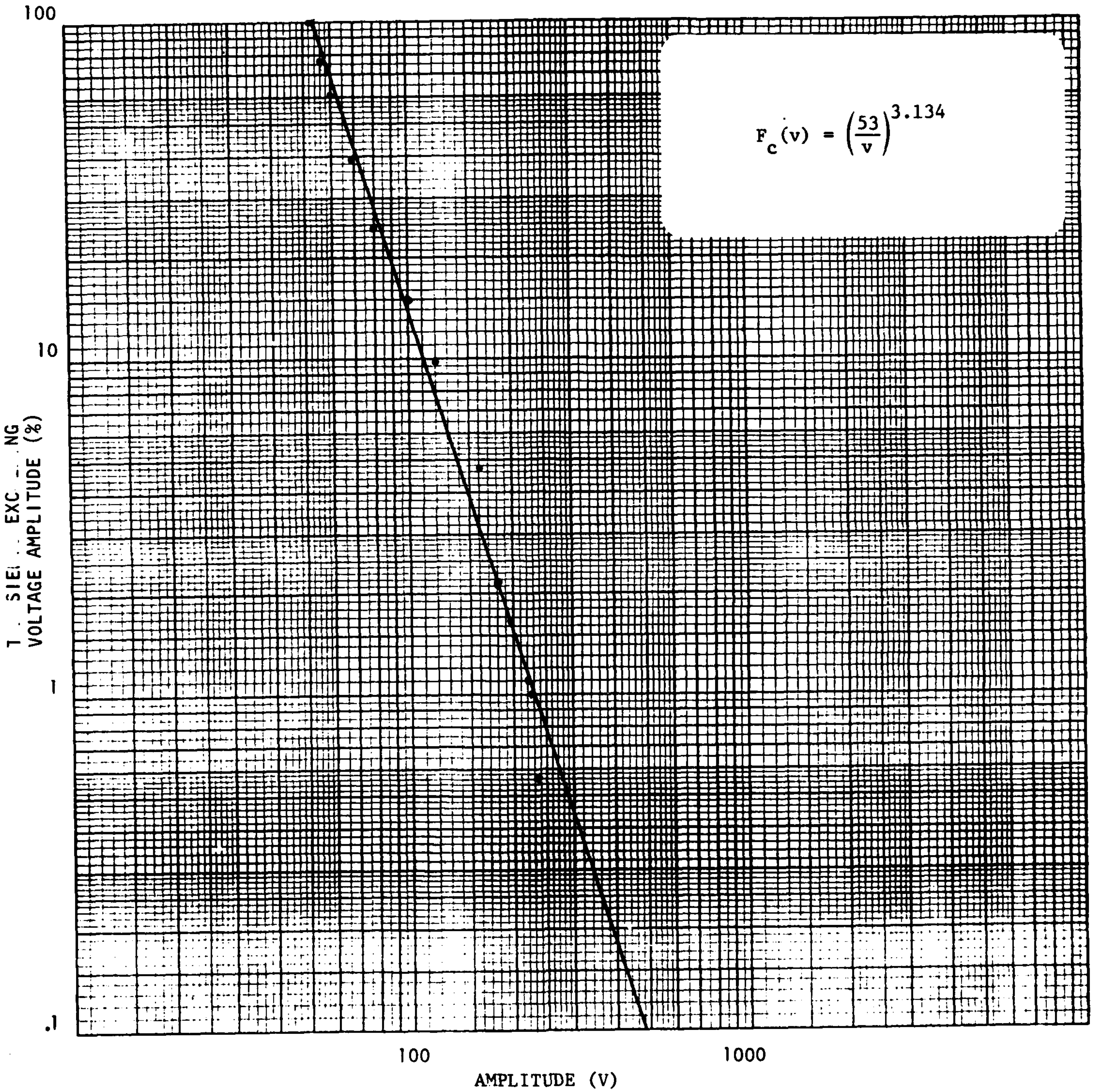


Figure A-34. Peak Amplitude Distribution
Panel F (120V)
Radar Site, St. Thomas, VI

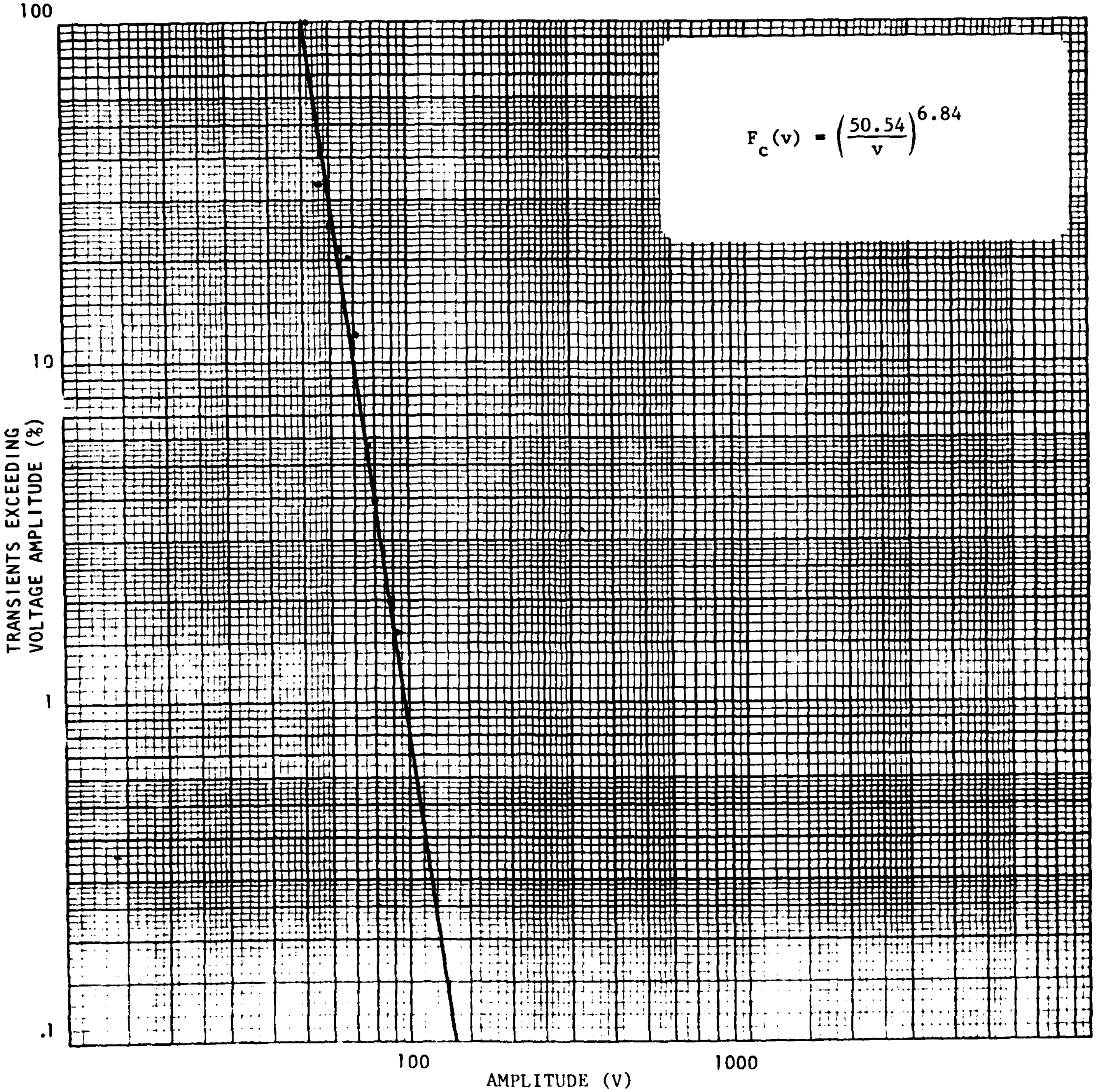


Figure A-35. Peak Amplitude Distribution
Load (120V)
Radar Site, St. Thomas, VI

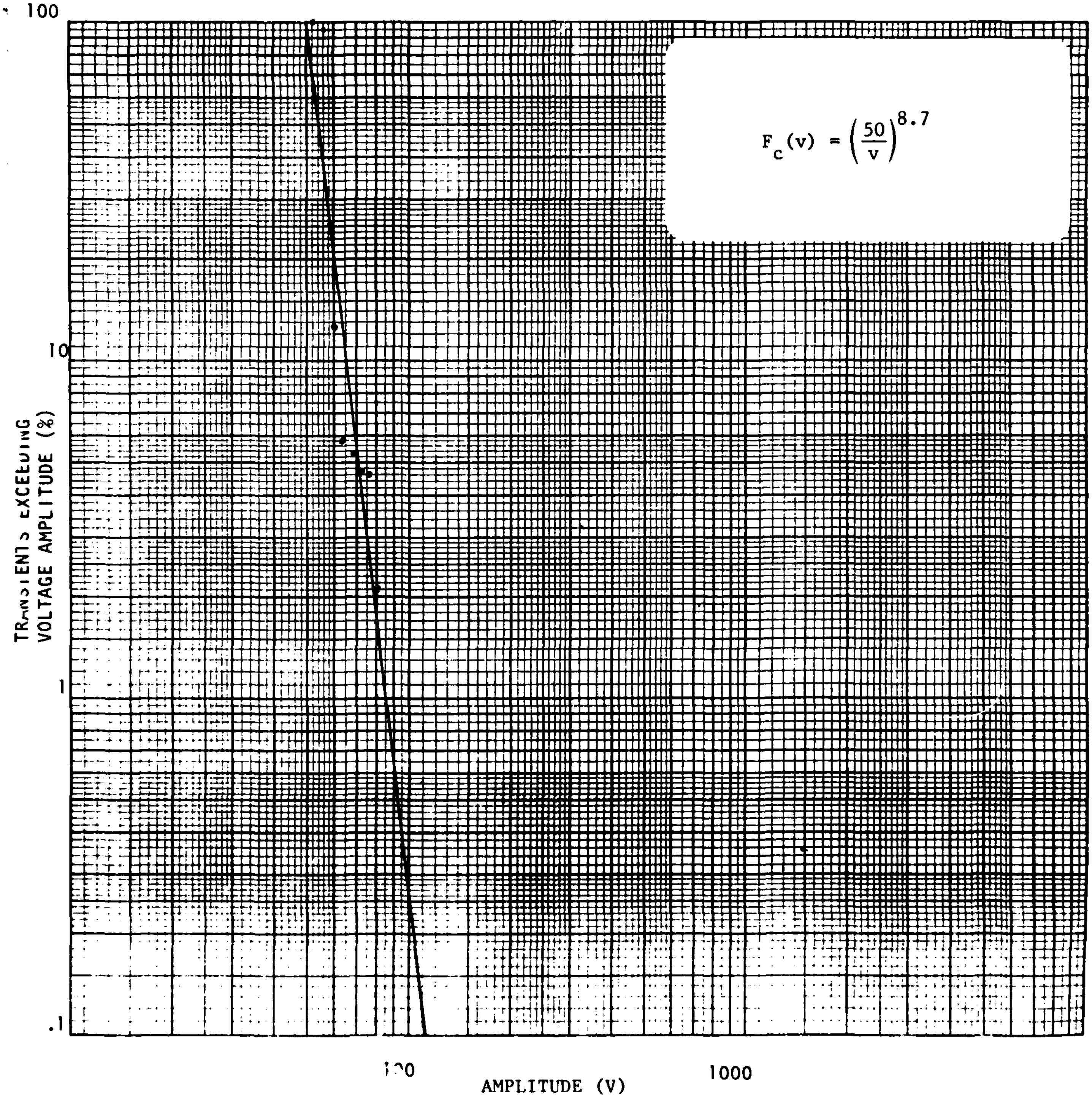


Figure A-36. Peak Amplitude Distribution
Source (120V)
Radar Site, St. Thomas, VI

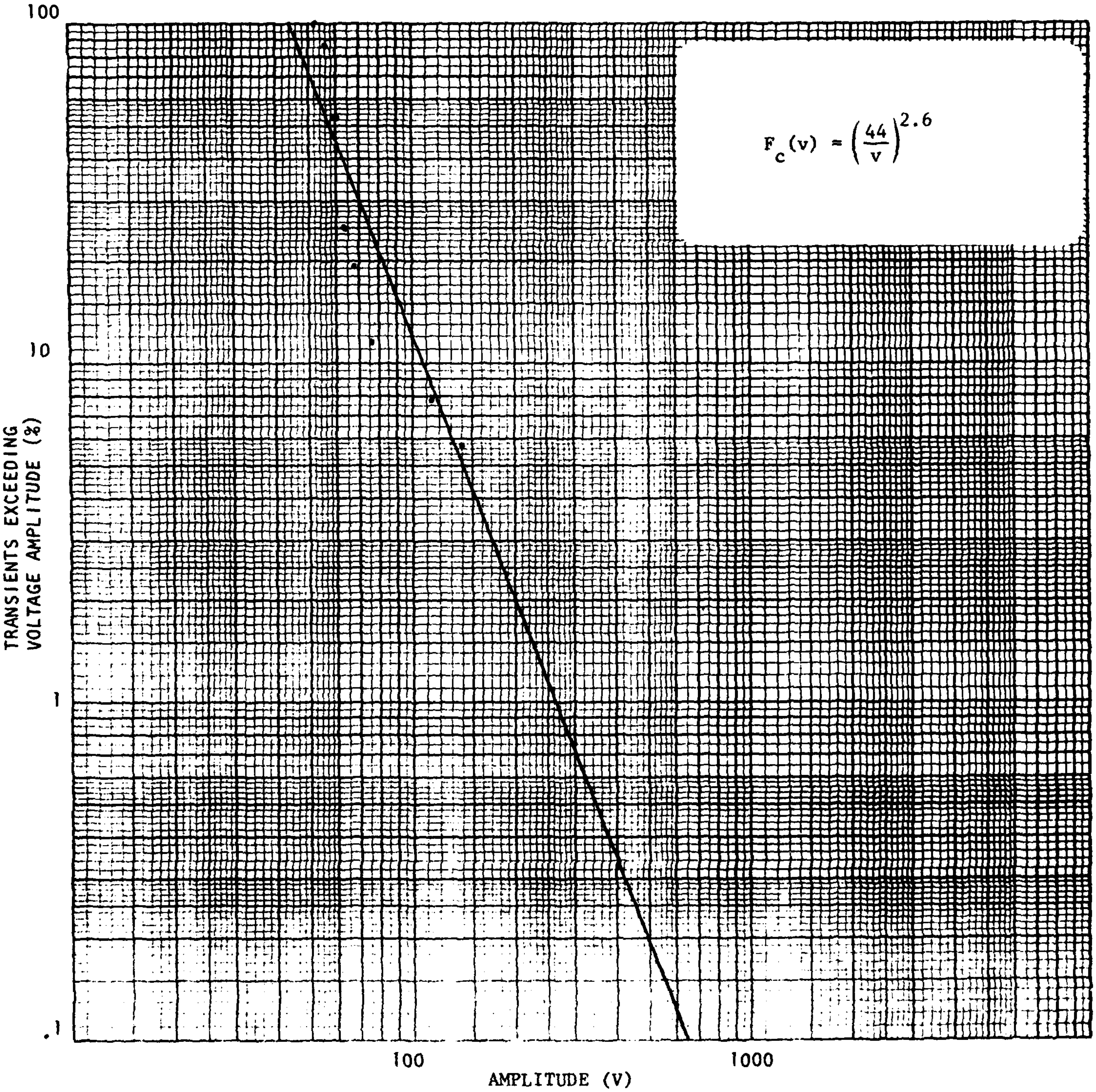


Figure A-37. Peak Amplitude Distribution
Air Conditioning (120V)
Radar Site, St. Thomas, VI

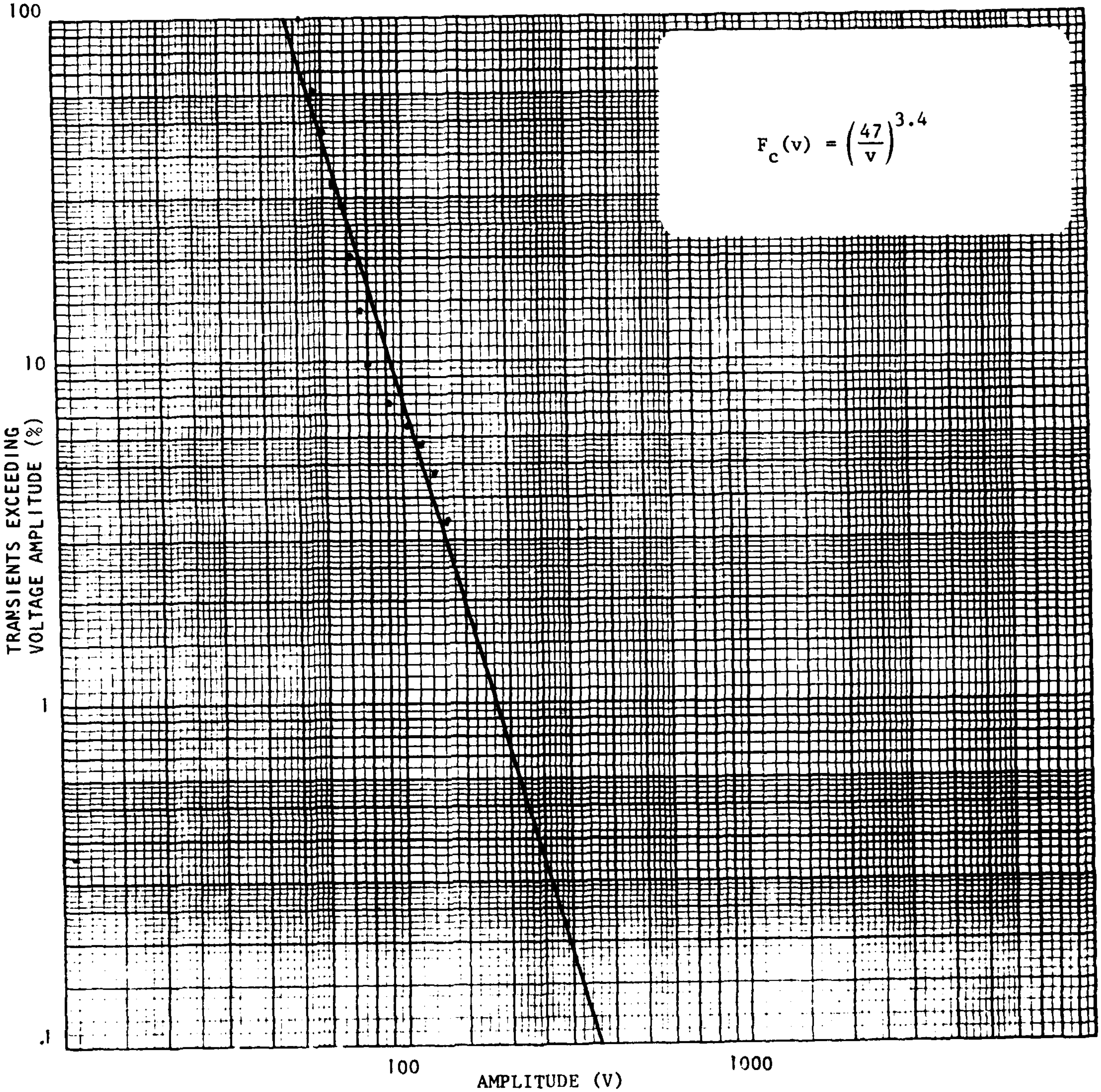


Figure A-38. Peak Amplitude Distribution
Panel E (120V)
Radar Site, St. Thomas, VI

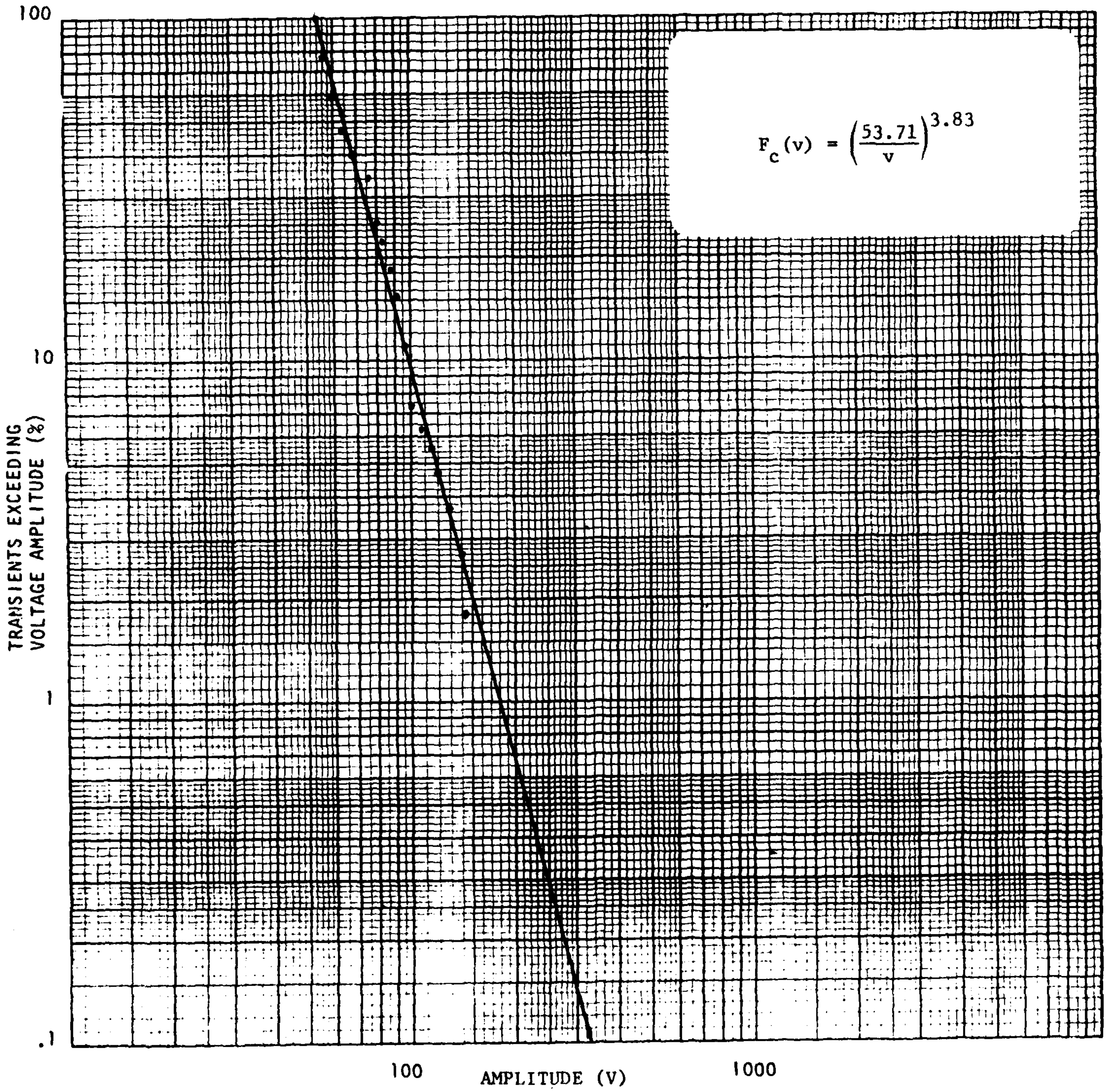


Figure A-39. Peak Amplitude Distribution
Power Pole (120V)
Radar Site, St. Thomas, VI

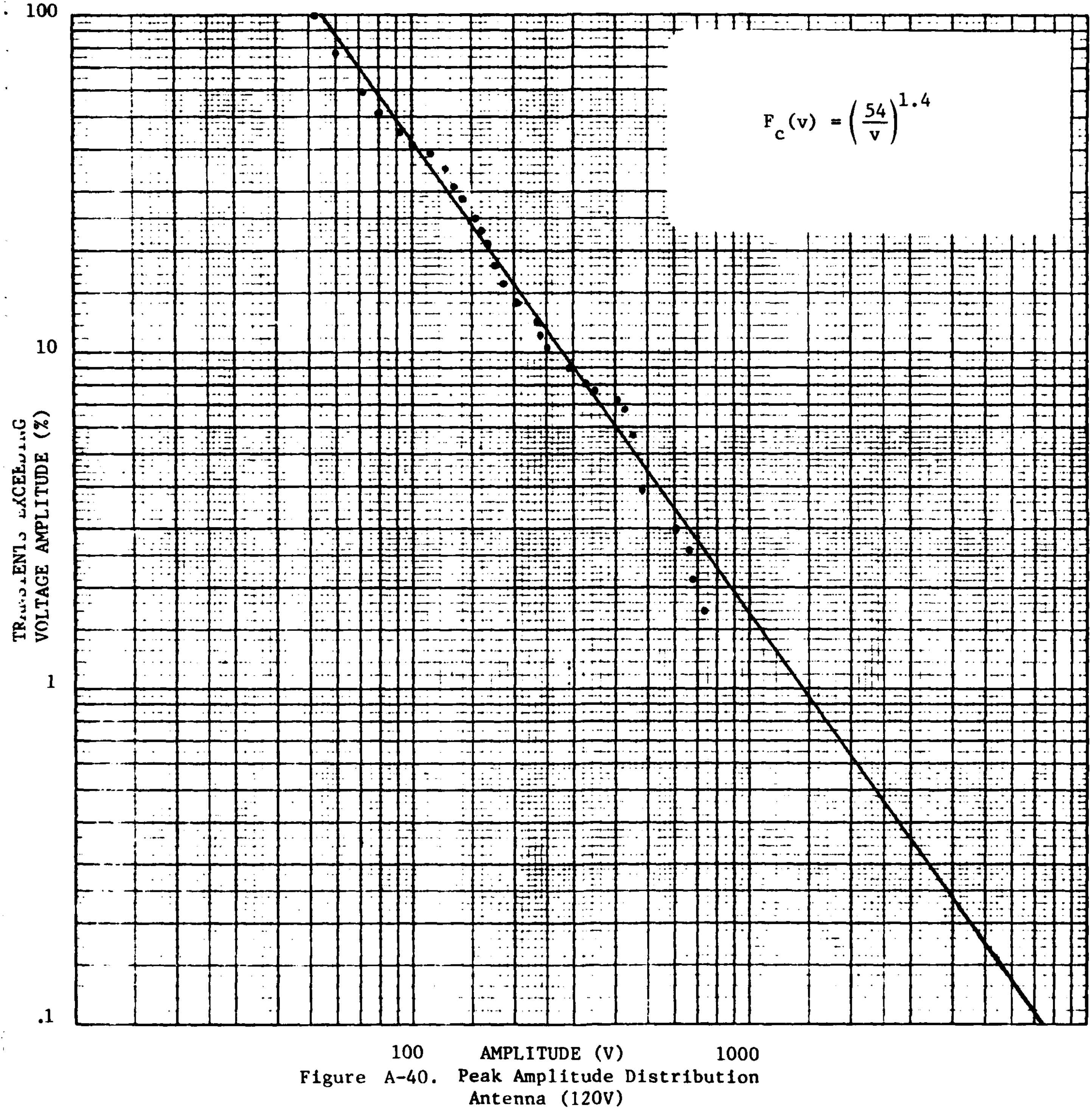


Figure A-40. Peak Amplitude Distribution
Antenna (120V)
Radar Site, St. Thomas, VI

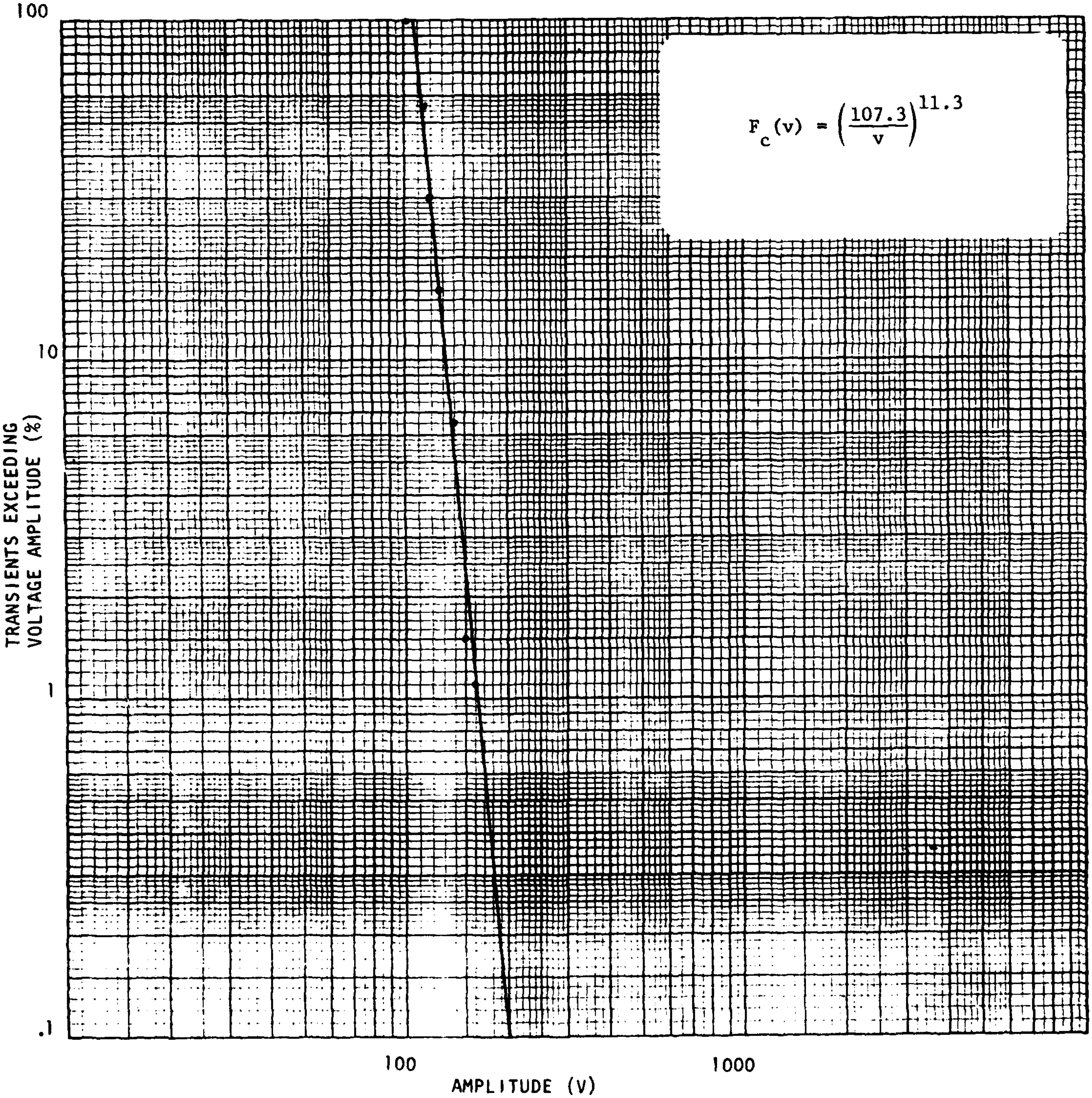


Figure A-41. Peak Amplitude Distribution
Equipment Hut, Power Pole (208V)
Anti-Personnel Intrusion Test Site, Eglin AFB, FL

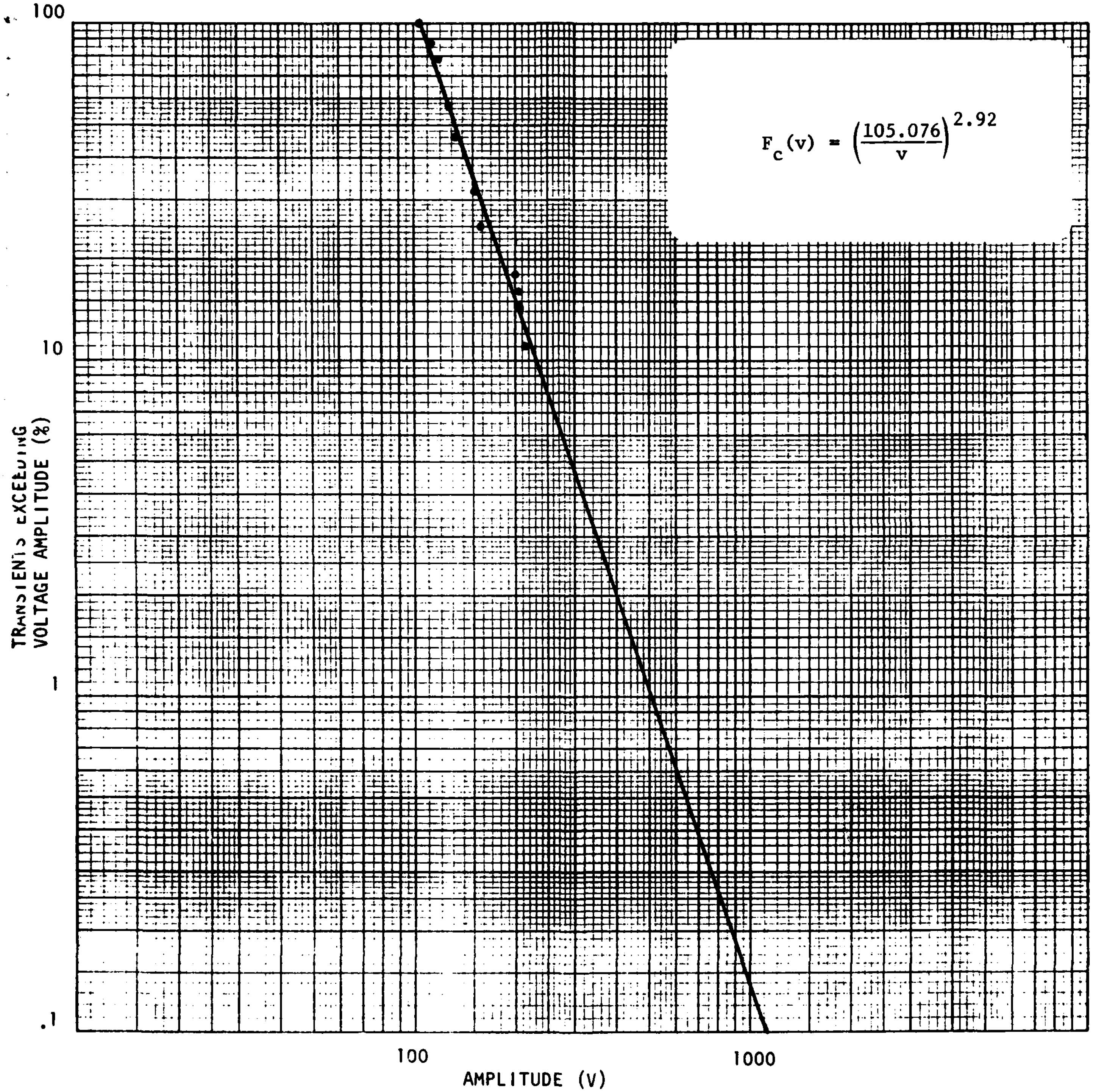


Figure A-42. Peak Amplitude Distribution
Pump House (208V)
Anti-Personnel Intrusion Test Site, Eglin AFB, FL

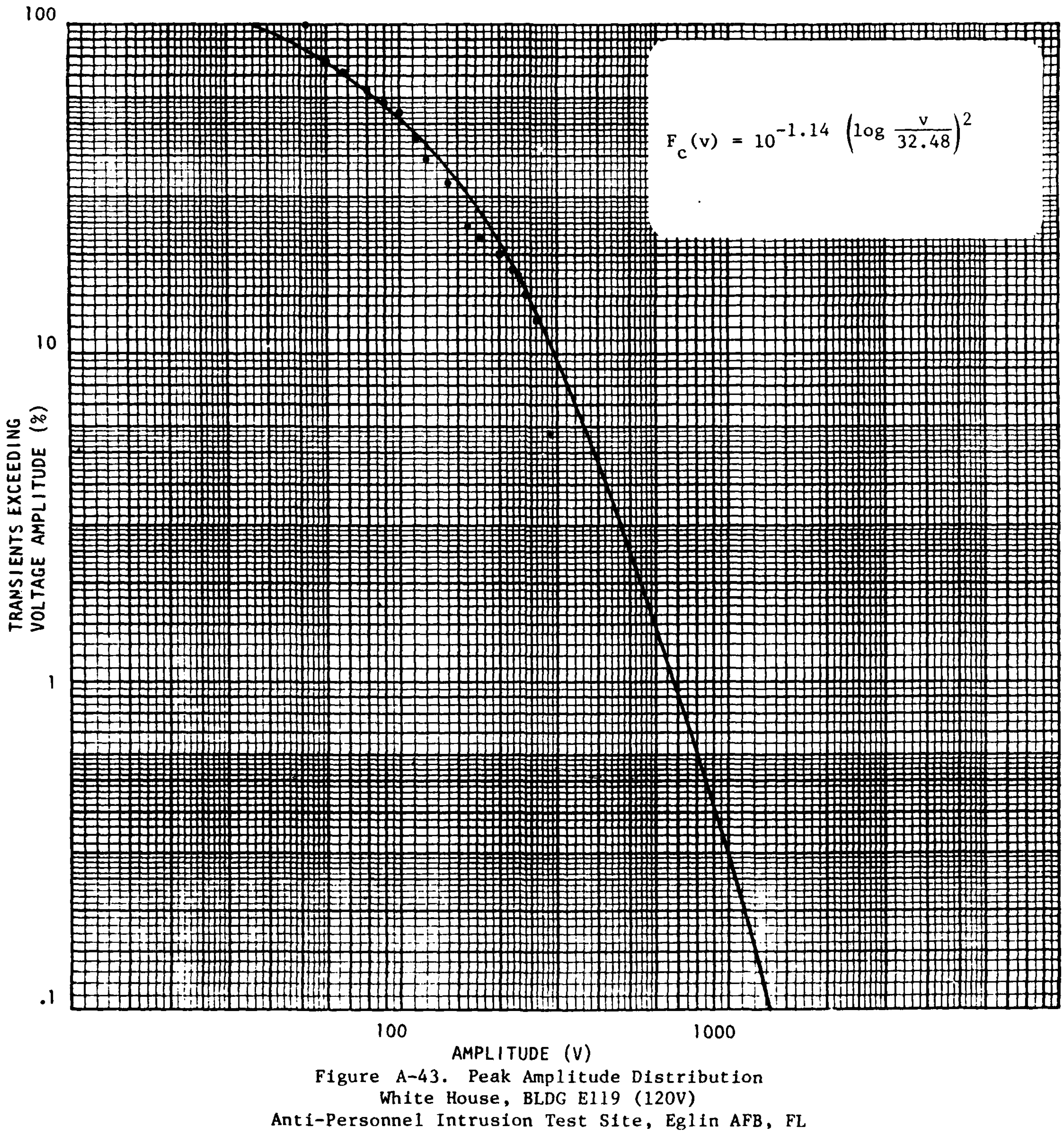


Figure A-43. Peak Amplitude Distribution
White House, BLDG E119 (120V)
Anti-Personnel Intrusion Test Site, Eglin AFB, FL

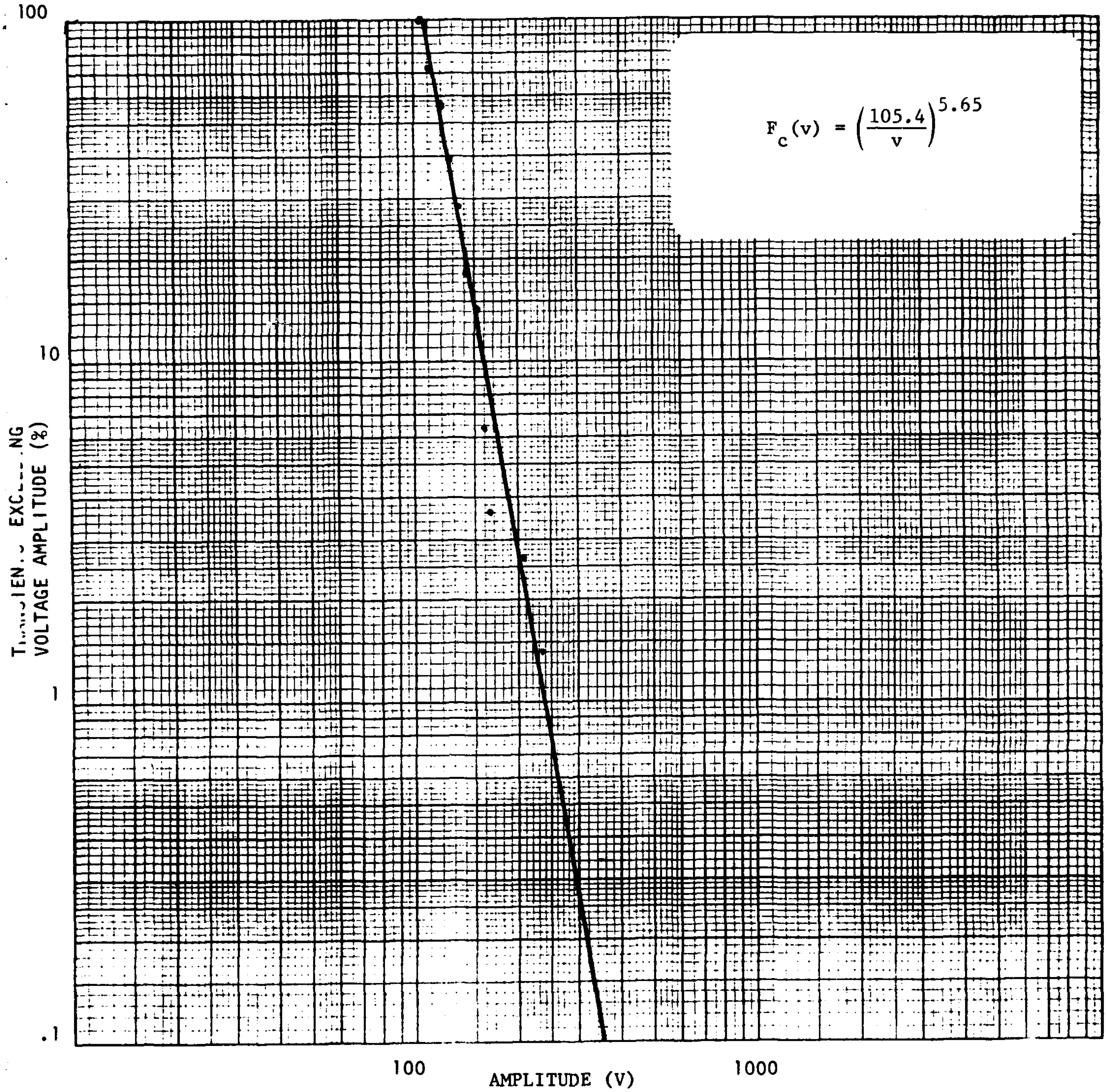


Figure A-44. Peak Amplitude Distribution
Facility Wall Box (120V)
FASOTRAGRUPAC, NAS Miramar, CA

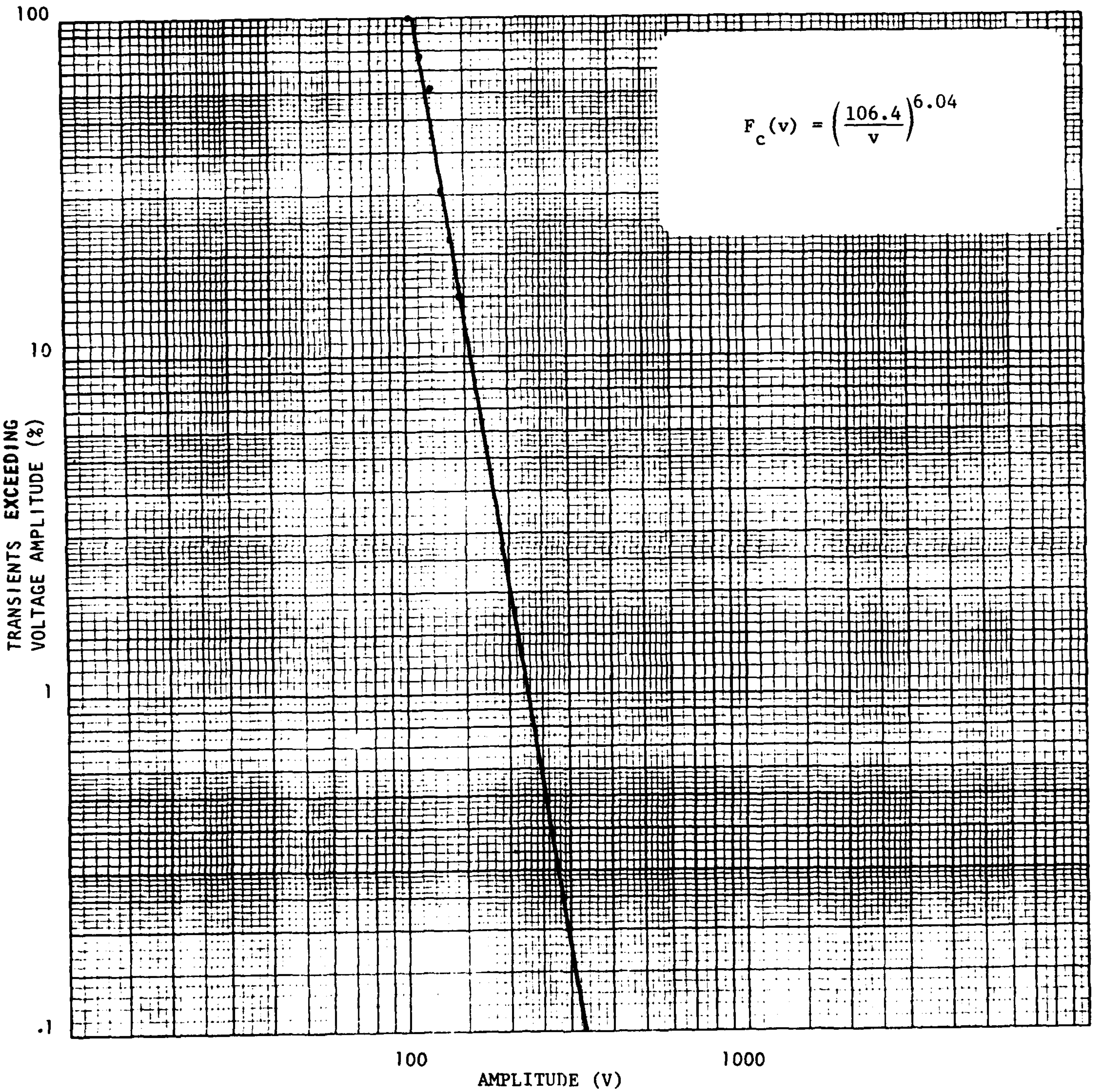


Figure A-45. Peak Amplitude Distribution
Main Power Panel (120V)
FASOTRAGRUPAC, NAS Miramar, CA

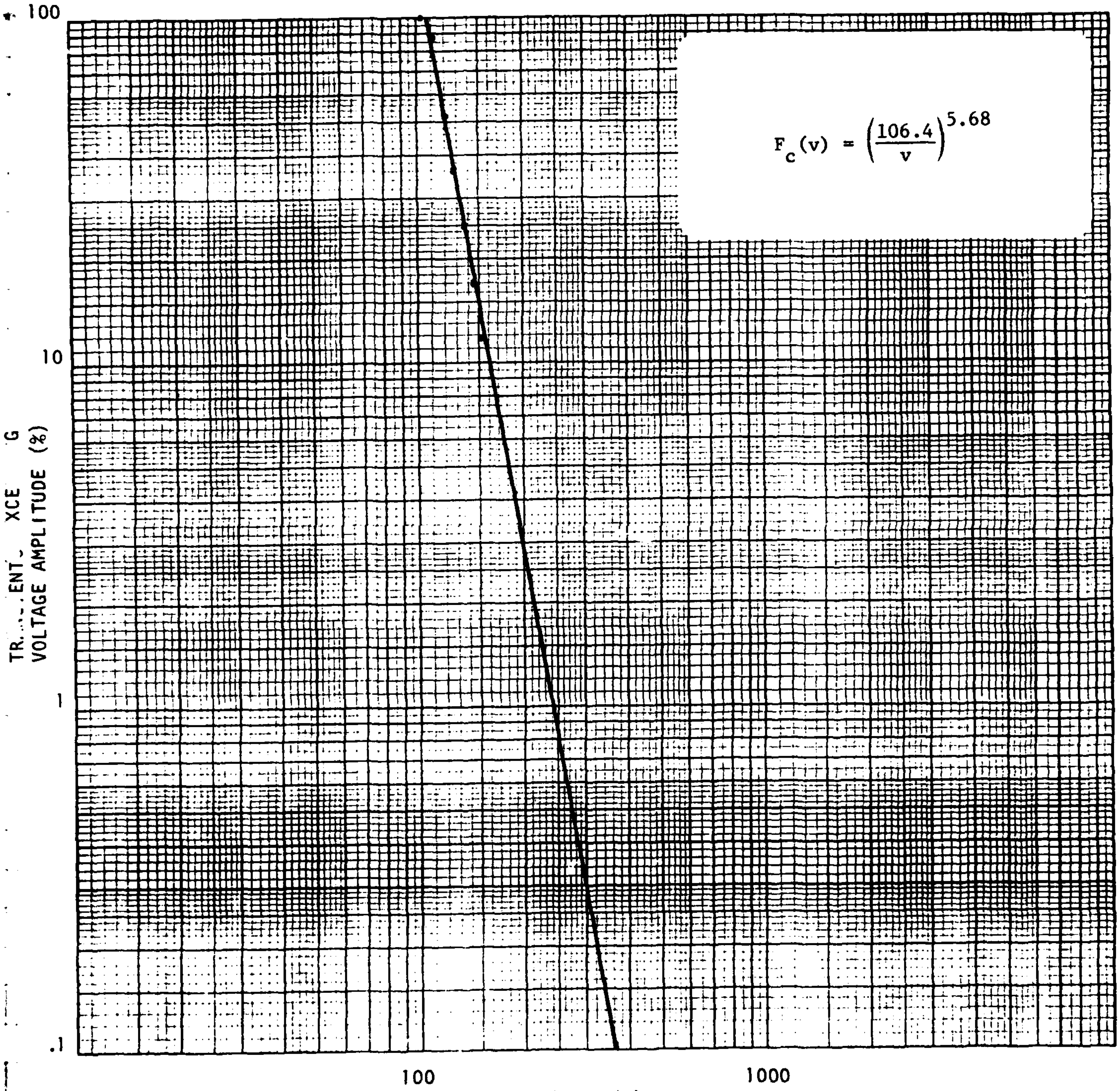


Figure A-46. Peak Amplitude Distribution
Computer Cabinet #7 (120V)
FASOTRAGRUPAC, NAS Miramar, CA

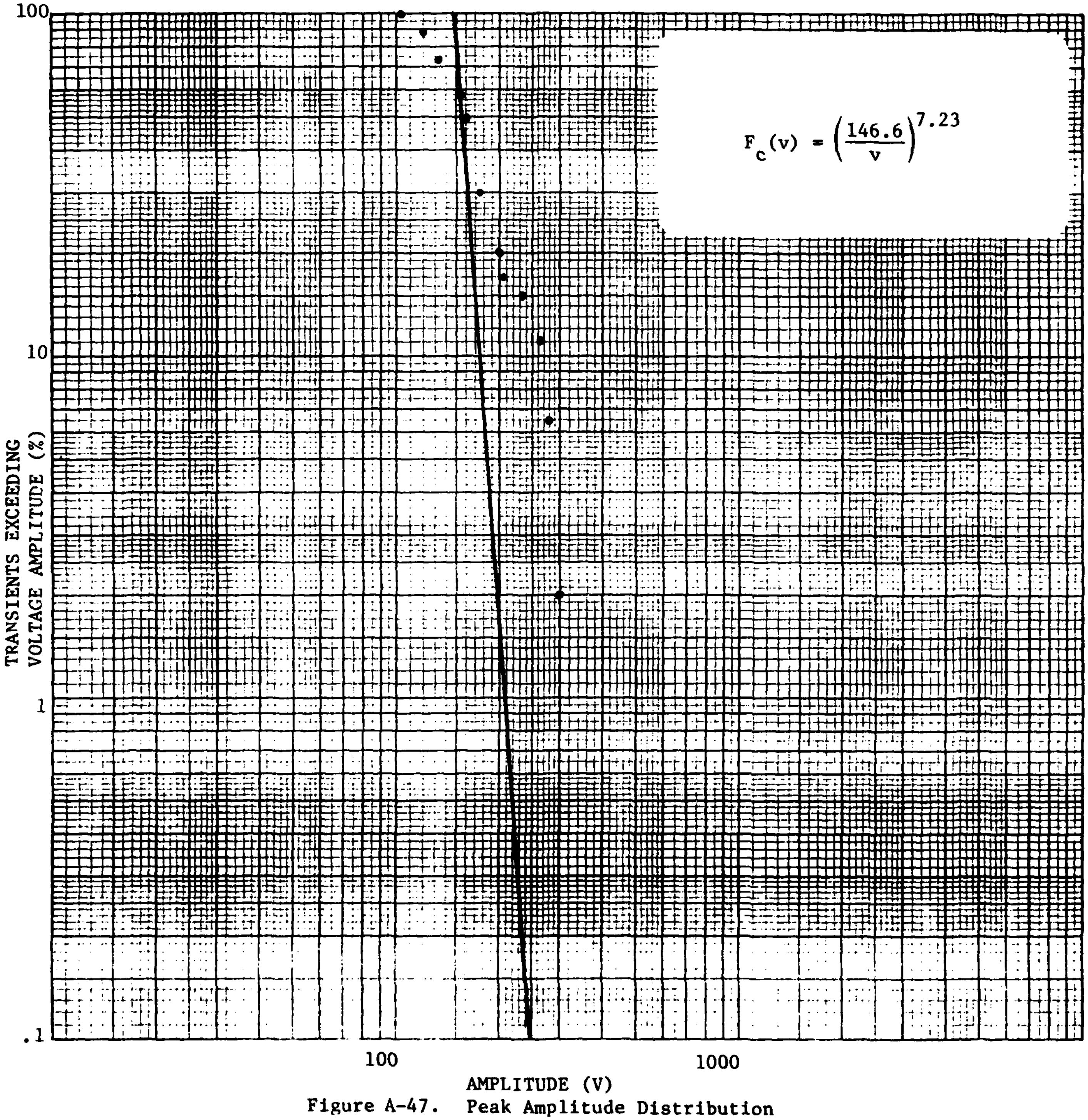


Figure A-47. Peak Amplitude Distribution
WST-1 Cabinet 1 (208V)
FASOTRAGRUPAC, NAS North Island, CA

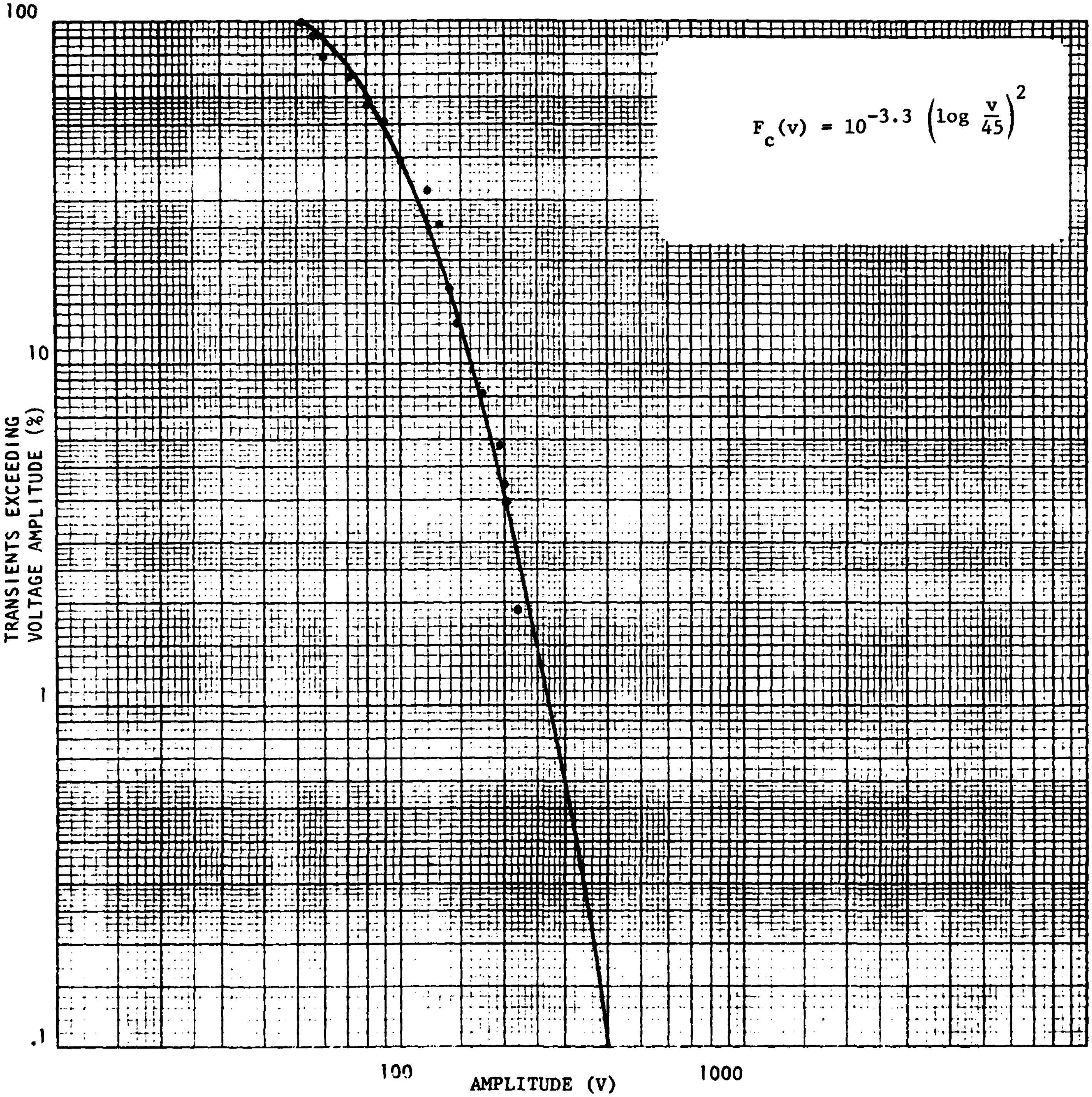


Figure A-48. Peak Amplitude Distribution
WST-3, Cabinet 1 (120V)
FASOTRAGRUPAC, NAS North Island, CA

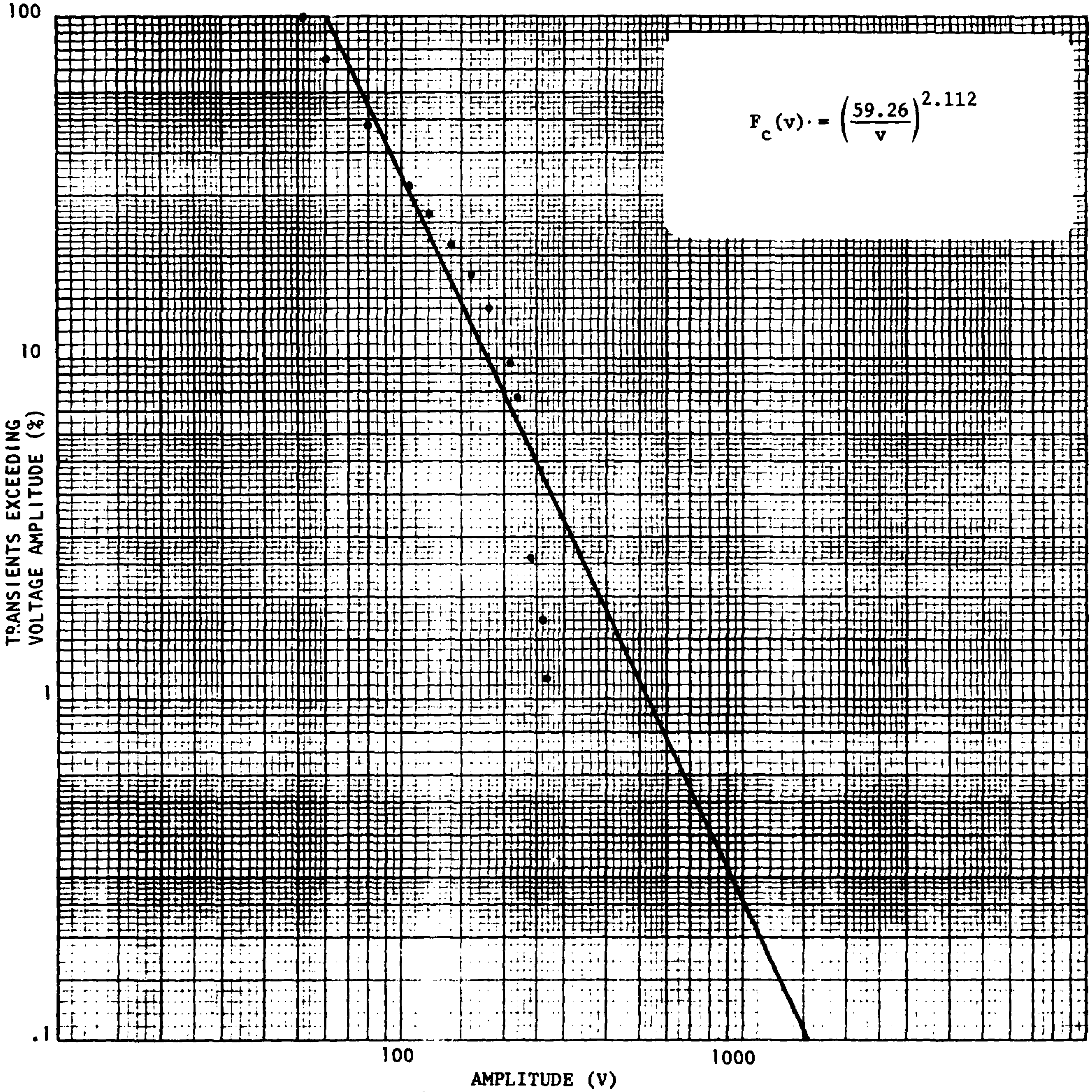


Figure A-49. Peak Amplitude Distribution
2500 AMP Panel (120V)
FASOTRAGRUPAC, NAS North Island, CA

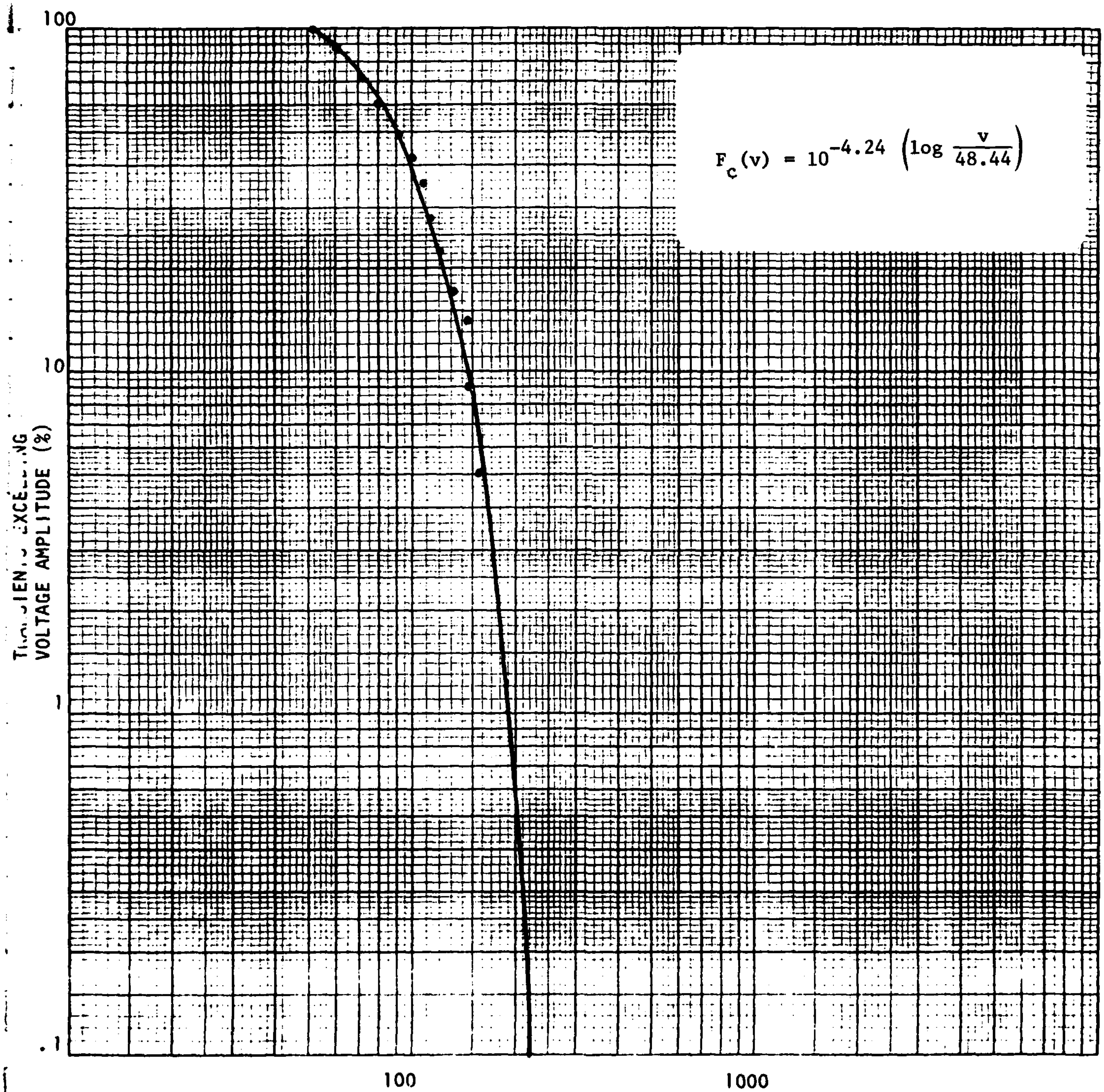


Figure A-50. Peak Amplitude Distribution
2000 AMP Panel (120V)
FASOTRAGRUPAC, NAS North Island, CA

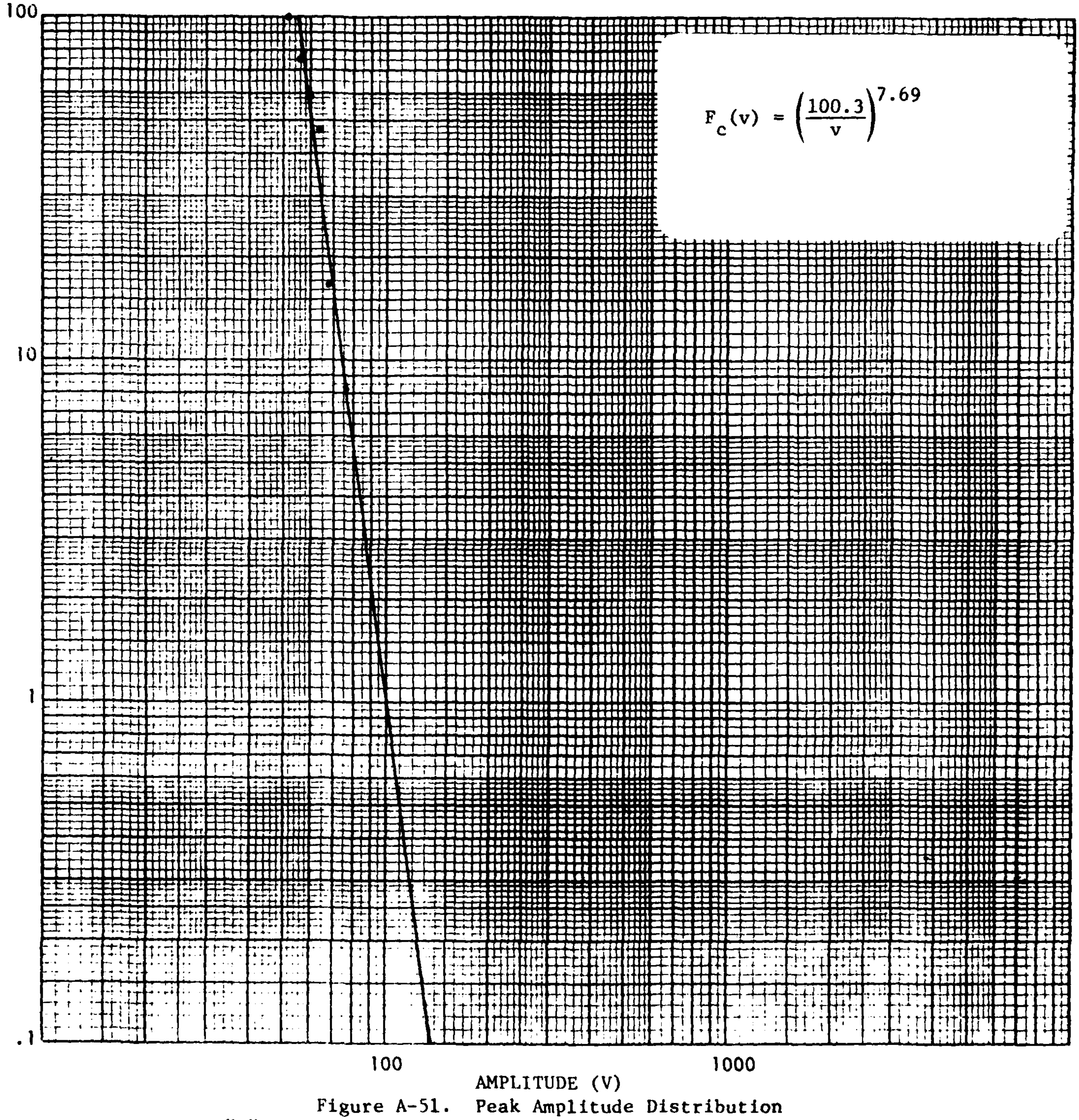


Figure A-51. Peak Amplitude Distribution
"R" Site, Tech Control - VCFT Primary Power Panel (120V)
Diego Garcia, Indian Ocean

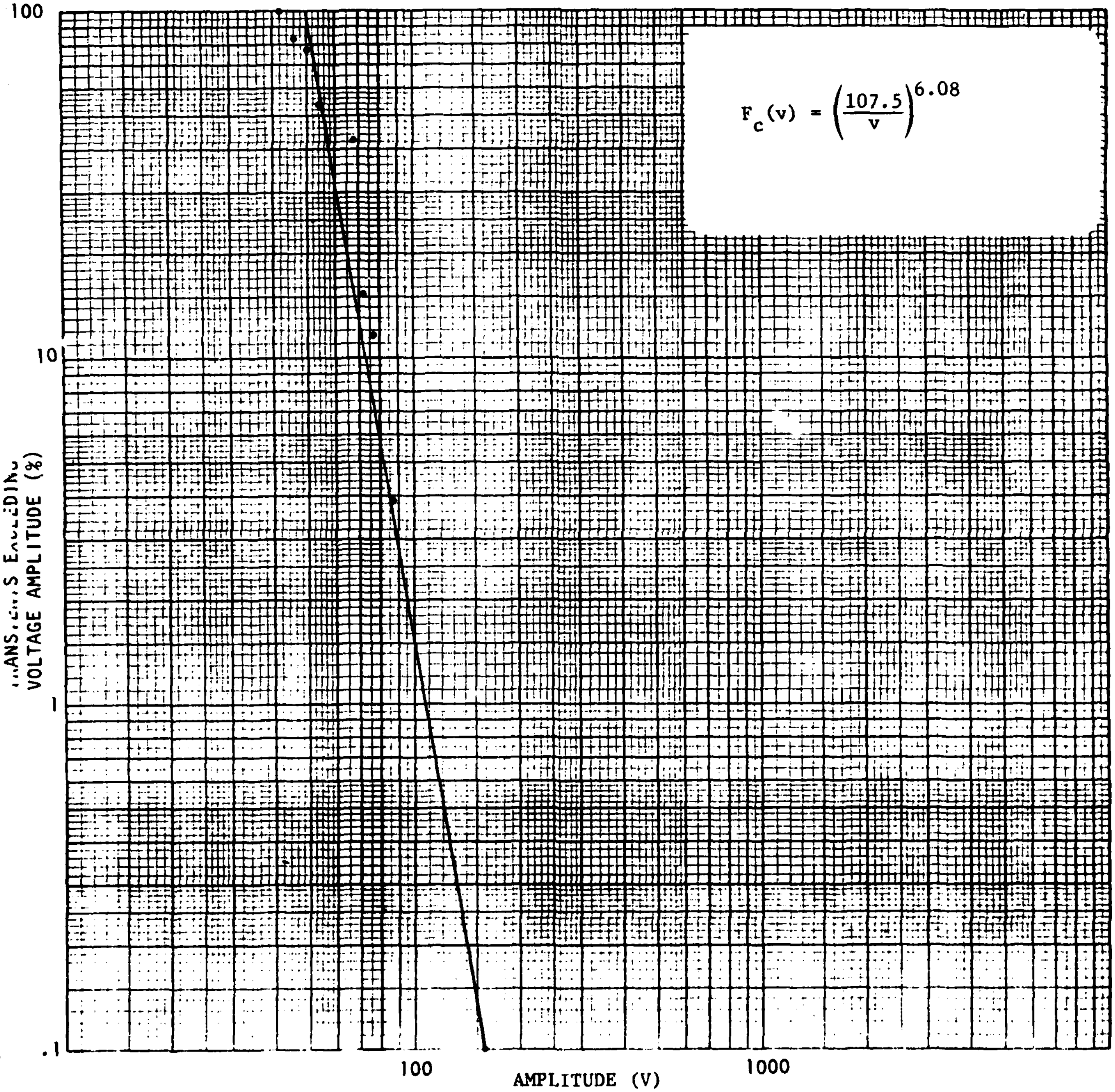


Figure A-52. Peak Amplitude Distribution
"R" Site, SATCOM-480 VAC Power Distribution Panel and
DCSS Van Tech Power (120V)
NAVCOMSTA, Diego Garcia, Indian Ocean

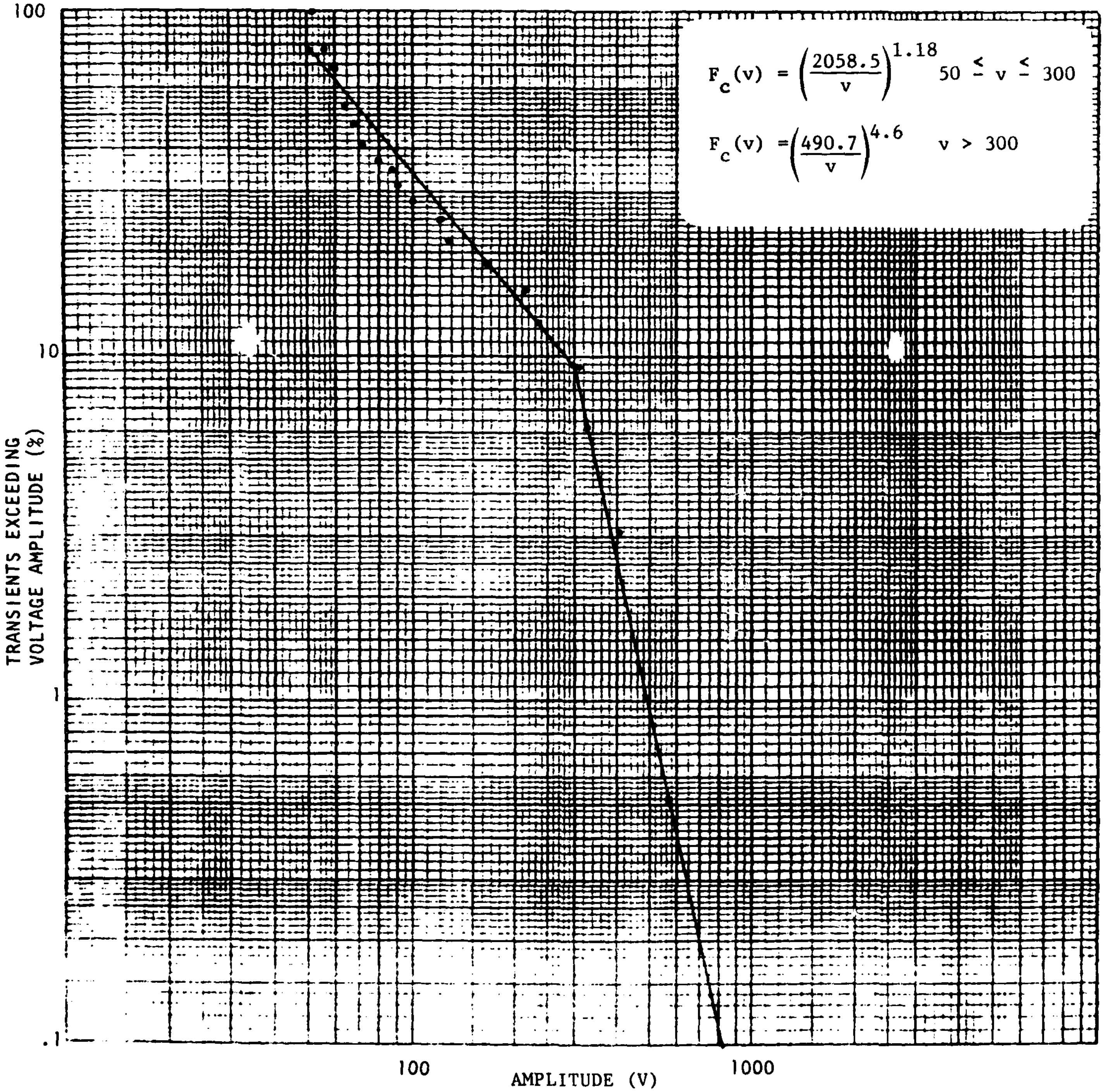


Figure A-53. Peak Amplitude Distribution
AN/FRT-85 Power Line Terminals (280V)
NAVCOMSTA, Diego Garcia, Indian Ocean

## APPENDIX B

## EFFECTS OF CHANGING SENSITIVITY LEVELS

This appendix deals with the problem of how to treat data obtained where the impulse sensitivity level has been changed during the monitoring period. To simplify the analysis, consider a hypothetical case with a sensitivity level of 50 volts initially and later raised to 100 volts during the monitoring period. We would like to investigate data types A and B where.

A: Transient data with amplitudes $\geq$ 50 volts

B: Transient data with amplitudes $\geq$ 100 volts

Obviously, data type B is a subset of data type A.

Let $N_A$ = total number of transients with amplitudes $\geq$ 50 volts

$N_B$ = total number of transients with amplitudes $\geq$ 100 volts

$N_v$ = total number of transients with amplitudes $\geq$ v volts $v \geq 100$

Thus $N_v$ is the same for both A and B. Similary, if $P_A(v)$ and $P_B(v)$ denote the probabilities that a transient will occur with amplitude > v for A and B respectively, where v > 100, then

$$P_A(v) = \frac{N_v}{N_A} \quad ; \quad P_B(v) = \frac{N_v}{N_B}$$

and $$P_A(v) < P_B(v) \text{ since } N_A > N_B$$

In particular $$P_B(v) = \frac{N_v}{N_B} = \left(\frac{N_v}{N_A}\right)\left(\frac{N_A}{N_B}\right)$$

Thus, the data between A and B differ by a multiplicative factor which is a constant. It follows, therefore, that if Case A has a log-log linear fit so does Case B. In fact, both have the same slope the only difference being a displacement of the graph. Specifically, if the log-log linear fit for Case A yields a distribution of the form

$$\left(\frac{V_o}{V}\right)^a \qquad \text{Case A}$$

the log-log linear fit for Case B yields the distribution.

$$\left(\frac{N_A}{N_B}\right)^a \frac{V_o}{V} \quad ; \qquad \text{Case B}$$

Of course, Case A is incorrect since we have suppressed all transients occurring with voltage amplitudes < 100 after we have raised the sensitivity level. Therefore, the correct expression for the distribution is given by Case B.

## APPENDIX C

## MODIFIED 120V CUMULATIVE STATISTICS

As indicated in the body of this report, a couple of instances occurred during which only a summary of transient activity was obtained, and not detailed information on each transient that had occurred. For example, at both the RAPCON and GCA Radar test locations at the Key West site there were instances where only the total number of transients, the transient rate and the average transient amplitude were known over a specified period of time. At the GCA Radar test location, for example, 388 impulses occurred at the rate of one every 5 minutes, with an average amplitude of 100 volts. In addition, there were instances where the transient threshold level was raised during the course of the experiment; this happened in both the TACAN and GCA Radar test locations at Key West.

In plotting the cumulative amplitude statistics contained in this report, the transient amplitudes in the above cases were included, notwithstanding the constraints on that data. However, it was considered of interest to look at the distributions if such data were excluded. Accordingly, the cumulative amplitude statistics were recomputed, excluding TACAN and GCA Radar test location data as well as a portion of the RAPCON test location data, for which only summary transient information was available.

Both sets of data are shown in Figure C-1. Curve I is identical to Figure 3-19 of the report and is the result of using all 120 volt line transient amplitude information; it is defined by the expression $F_c(v) = \left(\frac{65.45}{v}\right)^{3.62}$. Curve II is based on the same data, less the TACAN and GCA Radar data and the RAPCON data for which only transient summary data were recorded; it is defined by $F_c(v) = \left(\frac{59.4}{v}\right)^{3.302}$. As shown in Figure C-1, the two curves are nevertheless very similar.

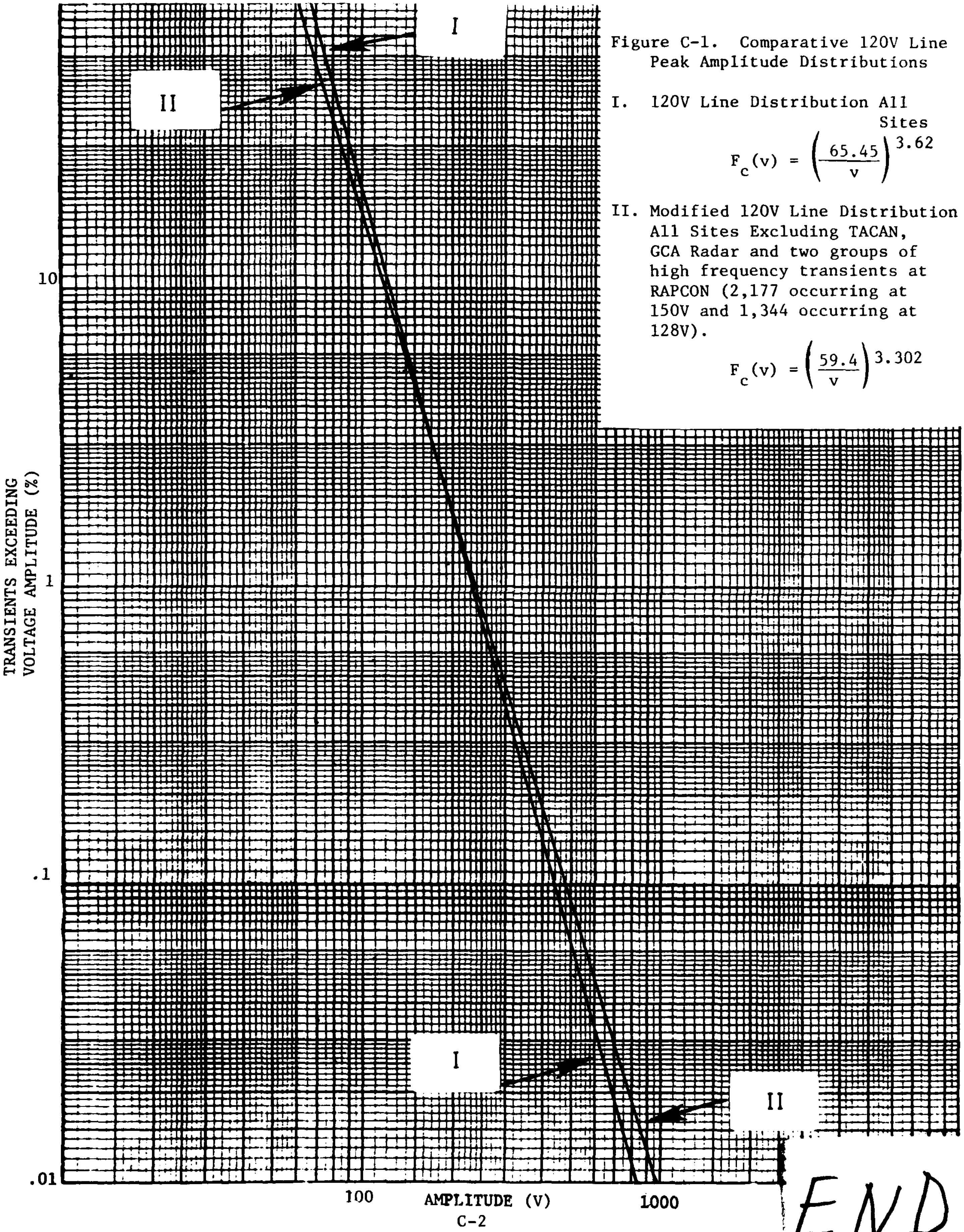


Figure C-1. Comparative 120V Line Peak Amplitude Distributions

I. 120V Line Distribution All Sites

$$F_c(v) = \left(\frac{65.45}{v}\right)^{3.62}$$

II. Modified 120V Line Distribution All Sites Excluding TACAN, GCA Radar and two groups of high frequency transients at RAPCON (2,177 occurring at 150V and 1,344 occurring at 128V).

$$F_c(v) = \left(\frac{59.4}{v}\right)^{3.302}$$



END